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INDIAN ROADS CONGRESS

(Established 1934) *(Registered 1937)*

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29. Diwan Bahadur V.G. SHETE, Retired Consulting Public Health Engineer to the Government of Bombay, 322/2, Sadashiv - Peth, Poona.

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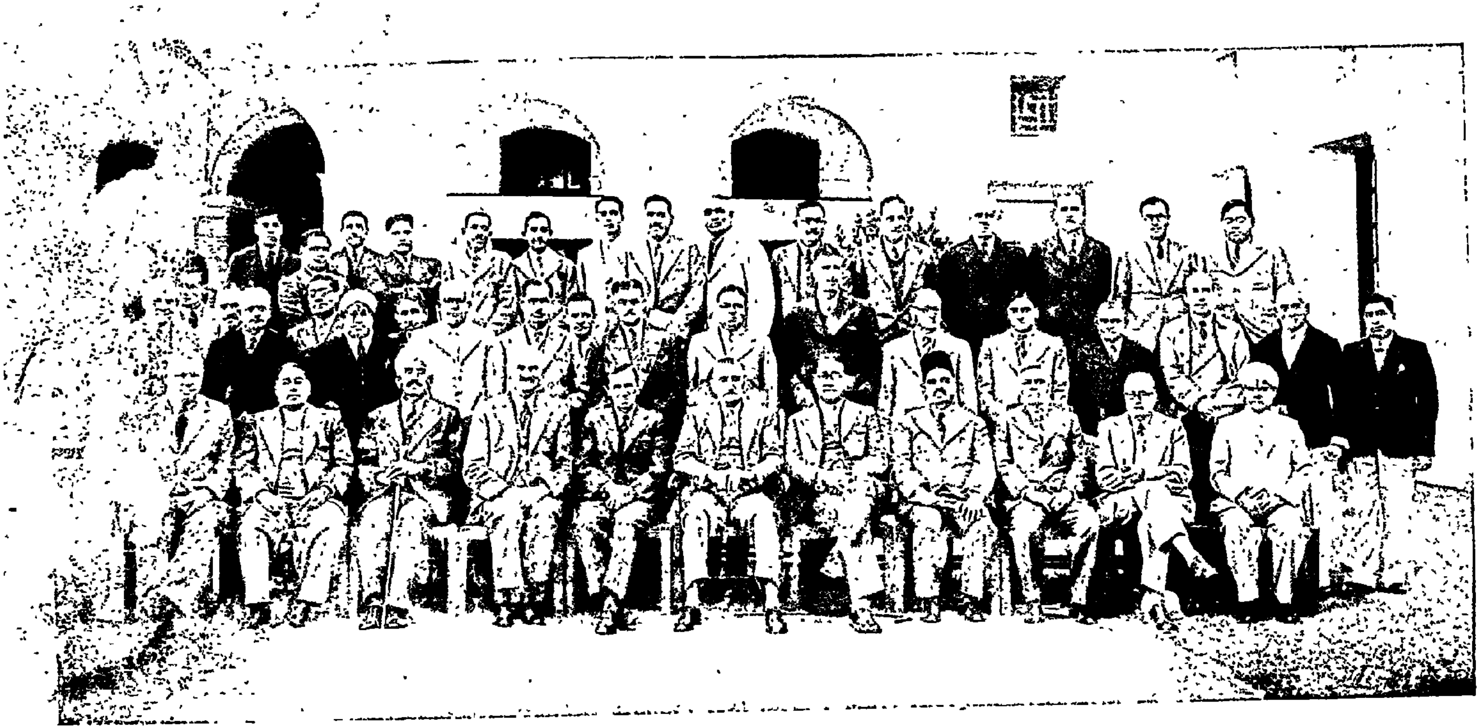
33. Mr. N. DURRANI, District Board Engineer, Nellore District, Nellore.



Seventh Indian Roads Congress, Delhi, January, 1941.

Proceedings of the Seventh Meeting of the Indian Roads Congress.

Volume VII, Part I. Delhi. January 1941.

CONTENTS.

PAPERS.

Proceedings of the Seventh Meeting of the Indian Roads Congress held at Delhi on January 23 to 28, 1941.

The Council of the Indian Roads Congress met at 10-30 A M. on *January 23, 1941, at the New Delhi Town Hall, New Delhi.*

The following members of the Council were present:—

Mr. K. G. Mitchell, C.I.E.,
Consulting Engineer to the Government of India (Roads),
New Delhi.

Sri A. Lakshminarayana Rao,
Deputy Chief Engineer, Communications,
Chepauk, Madras.

Mr. R. A. Fitzherbert,
Superintending Engineer, Central Circle,
Public Works Department, Poona.

Mr. Mahabir Prasad,
Offg Chief Engineer, United Provinces,
Public Works Department, Lucknow.

Mr. R. Trevor-Jones, M.C,
Chief Engineer, Punjab, Public Works Departmen
Buildings and Roads Branch, Lahore.

Mr. P V. Chance,
Chief Engineer, Central Provinces and Berar,
Public Works Department, Nagpur

Mr. S. A. Amir,
Executive Engineer, Bhagalpur Division,
Public Works Department, Bhagalpur.

Mr. K. E. L. Pennell, M C.,
Chief Engineer, Assam,
Public Works Department, Shillong.

Mr. W. R. Fleury,
Executive Engineer, Sambalpur Division,
Public Works Department, Sambalpur.

Mr. H. B Parikh,
Special Road Engineer in Sind,
Karachi-Saddar.

Sardar Bahadur T. S. Malik, C.I.E.,
Chief Engineer, Central Public Works Department,
New Delhi.

Mr. Syed Arifuddin,
Chief Engineer, Public Works Department,
Hyderabad-Deccan.

Mr. M. S. Duraiswamy Ayyangar,
Chief Engineer, Travancore State,
Public Works Department, Trivandrum.

Rao Bahadur K. J. Gandhi,
State Engineer, Junagad State,
Public Works Department, Junagad.

Mr. B. R. Garudachar,
Superintending Engineer, Mysore Circle,
Public Works Department, Mysore.

Mr. A. C. Malhotra,
Chief Engineer and Secretary, Patiala State,
Public Works Department, Patiala.

Mr. K. L. Nanda,
Divisional Engineer, Palaces Division,
Jammu Tawi.

Mr. W. J. Turnbull,
The Shalimar Tar Products (1935) Ltd.,
6, Lyons Range, Calcutta.

Mr. H. E. Ormerod,
The Concrete Association of India,
Esplanade House, Waudby Road, Bombay.

Mr. D. Nilsson,
Messrs. J. C. Gammon Limited,
Hamilton House, Graham Road, Ballard Estate, Bombay.

Mr. Ian A. T. Shannon,
The Burmah-Shell Company,
Hongkong House, Calcutta.

Diwan Bahadur V. G. Shete,
Retired Consulting Public Health Engineer to the Government of Bombay,
322/2, Sadashiv Peth, Poona.

Mr. N. V. Modak,
City Engineer, Bombay Municipality,
Bombay.

Mr. G. B. Vaswani,
Assistant Engineer, Roads,
Karachi Corporation, Karachi.

Mr. W. L. Murrell, O.B.E.,
Superintending Engineer, North Bihar Circle,
Public Works Department, Muzaffarpur.

Mr. S. Bashiram,
Superintending Engineer, Roads,
Public Works Department, Buildings and Roads Branch, Lahore.

Mr. N. Durrani,
District Board Engineer, Nellore District,
Nellore.

Lt. N. K. Bhonsale,
Chief Engineer, Gwalior Public Works Department,
Gwalior.

Mr. K. S. Raghavachary, (Secretary)
Assistant to the Consulting Engineer to the Government of India (Roads), New Delhi.

Mr. Jagdish Prasad,
Assistant Executive Engineer,
Public Works Department, Agra.

The following members of the Indian Roads Congress also attended by special invitation the various tours of inspections :—

Mr. A. W. H. Dean, M.C., E.D.,
Superintending Engineer, Delhi Province, New Delhi.

Rai Bahadur M. S. Mathur,
Executive Engineer, Special Division No. 1,
Public Works Department, New Delhi.

Mr. H. P. Sinha.
Executive Engineer, Services Division,
Public Works Department, New Delhi.

Mr. C. W. Grant,
Executive Engineer, Provincial Division,
Public Works Department, New Delhi.

Mr. J. B. Vesugar,
Superintending Engineer, I Provincial Circle,
Public Works Department, Buildings and Roads Branch, Lahore.

Mr. S. R. Mehra,
Executive Engineer, III Lahore Provincial Division,
McLeod Road, Lahore.

Mr. R. N. Dogra,
Sub-Divisional Officer, Public Works Department, Lahore.

Mr. C. J. Fielder,
The Shalimar Tar Products (1935) Limited,
6, Lyons Range, Calcutta.

Mr. Allan Stuart-Lewis,
The Concrete Association of India,
Oriental Buildings, The Mall, Lahore.

Rai Sahib Hari Chand,
District Engineer, The Concrete Association of India
70, Queensway, New Delhi.

Mr. Hugh James,
The Burmah-Shell Company,
Burmah-Shell House, New Delhi.

Mr. I. N. Khanna,
9, Babar Road, New Delhi.

The Session was formally opened by the Hon'ble Sir A. G. Clow, C.S.I., C.I.E., I.C.S., Member of Governor-General's Executive Council, in charge of the Departments of Communications and Railways, on the 23rd January, 1941.

In asking the Hon'ble Member to open the Session Mr. K. G. Mitchell, C.I.E., I.S.E., Consulting Engineer to the Government of India (Roads), President of the Indian Roads Congress, delivered the following address:—

Just over 6 years ago there was convened in Delhi, at the invitation of the Government of India, a meeting of 73 Engineers of Provinces and States, and representatives of businesses connected with roads, from which meeting the Indian Roads Congress resulted. For the first and three subsequent meetings the entire cost was defrayed by the Government of India from the Road Fund. Subsequently, the Governments of Provinces and States agreed to defray the expenses of their delegates (who must themselves be subscribing members of the Congress).

2. From its inception, the Congress has steadily grown although there are still many who would, we feel, benefit by joining. The attendance at annual meetings also has been greater since Provinces and States were free to decide how many delegates they would send, than when the Government of India paid the bill. The attendance at our last full meeting was 121.

3. These meetings require much organization in advance, and some months ago the question was whether the full Seventh Session should be held on this occasion, or whether, as a war economy, it should be abandoned. On the one hand, we believe that the Congress is definitely useful, and that the expense of annual meetings, divided over all Provinces and a number of States, is trifling. On the other hand was the feeling that, in the aggregate, the expenditure is substantial, and that it should, for the present, be avoided. After reference to the Council and to Provincial Governments, we reached the compromise of having a meeting of the Council only. This should in many ways prove an advantage since the Council has much business to transact for which there is insufficient time when full sessions are in progress and at the same time have advantage of the presence of local members.

4. That is the reason why this meeting is numerically small. We would have preferred that, here in Delhi, we should have been at full strength, since it is here that we have the privilege of meeting you, Sir, the Member of the Executive Council in-charge of the Department of Communications. It is indeed possible that our next full meeting will be held in Delhi, before we go on our rounds again. Despite our small numbers, however, our welcome to you and to Hon'ble Mr. Roy is not the less cordial.

5. Before I proceed, I must refer to the great loss sustained by us in the death recently of Rai Bahadur S. N. Bhaduri for many years Chief Engineer, Gwalior and Diwan Bahadur N. N. Ayyangar, Chief Engineer, Mysore who were two of the original members of the Congress and of the Council, and Vice-Presidents of the Congress. They were also great

builders of bridges and of roads of which the roads of Gwalior and Mysore show many fine examples. We shall greatly miss their genial presence at our meetings and the benefit of their ripe experiences.

6. Sir, it is natural and inevitable that the first question, which should arise in connection with this meeting, is that of the activities of this Congress in relation to the war. Last year I expressed some apprehension, lest further retrenchment in the provision for road maintenance become necessary, because, where the provision has already been severely pared, further reduction must mean deterioration. Moreover, we now see widespread expansion of the army on wheels all around us, and it sometimes appears to be forgotten that it is not possible to separate into water-tight compartments the subject of the roads and their maintenance, and that of the intensity and type of transport which uses them. I repeat that the members of this Congress will do all in their power to preserve the roads from deterioration, but that, because of the expansion of the mechanised army, any cut in the provision for maintenance would be even more unfortunate than it appeared to us a year ago.

7. It is obvious, also, that the development of the army on wheels will require some adaptation or improvement of a number of important roads, particularly because since the development of railways, this consideration has not been prominent in our planning. In the immediate and emergent adaptation that may be necessary, the members of this Congress will welcome the opportunity of making some small contribution to the general war effort. Looking further ahead we see that the army of the future will be highly mobile, and while some of it may be able to travel across country, much will be dependent on good roads, and this aspect of road planning will not again, I believe, recede so far into the background as it had done in our time.

8. But at times like these, when the old order of many things is changing, it is natural to look to the happier and more distant future, and we in this Congress are concerned with that of roads in India, and their efficient development, as one of the most essential of public services. The conclusion of the last war saw the commencement of commercial motor transport in the mofussil of India brought about by the release of numbers of vehicles no longer required by the army. Likewise, at the end of this war, there will be very much larger numbers of vehicles and trained drivers looking for useful employment. This release will, I believe, much more than make up for the shrinkage in civil transport that may occur during the war and will be one of the many difficult problems of post-war adjustment, for which plans should be laid in advance. There is an immense milage of roads in India in areas unserved by any modern means of transport and the improvement of some part of that milage would ease the position. Failing any extension of the roads suitable for light intensities of motor traffic we shall, I fear, see a repetition of overcrowding and cut-throat competition on the main routes. Here is food for anxious thought and a field in which the members of this Congress, given the money necessary, could do much good. Clearly there is much more profitable work to be done than there will be money to do it with. Everything that we can do to improve what we call the 'road-rupee ratio' should be done.

9. Looking at the Indian road system as it is today, there appears to us to be a number of unsatisfactory features upon which this Congress feels itself entitled to express an opinion, but not to attempt to give a verdict. It was for this reason that at its meeting in Bombay just over a year ago the Congress adopted a resolution advocating the appointment of a strong committee to examine the whole road position, and to make recommendations. That resolution was forwarded to the Government of India, but we understand, and we readily appreciate the difficulties, that Government find themselves unable to move, owing, firstly to the preoccupations of the Central and Provincial Governments with the war, and, secondly, to the uncertain future consitutional and financial background against which any committee would have to consider the large issues involved.

10. While, however, we must regretfully recognise the inevitability of the postponement of the comprehensive review which we believe to be necessary, I may perhaps be permitted to refer shortly to certain of the salient points with which such a committee would, we feel, be at once confronted, giving at the same time my personal view thereon which generally represents, I believe, that of the members of this Congress. From the necessity of brevity, certain of the comments, which I offer, may appear to be somewhat blunt, but I disclaim any intention of implying that there are not other points of view on these matters.

11. Such a committee, then, would have to consider the following questions :—

Firstly, is the present condition of roads in India adequate to her needs, and, if not, does the policy followed in recent years, including the institution of the Central Road Fund, promise the necessary improvement?

In my opinion the answer to those questions must be in the negative.

Secondly, are the reasons for the defects in the present system financial, administrative or technical ?

Here the answer, I venture to say, is that all the three are concerned. As regards finance, I believe that a thorough enquiry would show that, for adequate development and maintenance, far larger sums would have to be provided than heretofore, and that the problem of making up arrears of development within any reasonable period of time transcends the possibilities of finance solely from revenue. If the cumulative loss through inefficient means of transport, rural stagnation and disease, and wear and tear of vehicles and cattle, were calculable, it would, I am confident, be found that the recovery of some of that loss would repay the expenditure of borrowed money. I also believe that the question of maintenance should be more squarely faced than sometimes appears to be the case. Much money has been spent at times in reconstructing roads, the maintenance of which had been neglected, and no public authority should ever spend money on road development without reasonable assurance that the funds for the future maintenance of those roads will not only be available, but will be provided.

12. On the administrative side there are the existing division, which, in some parts of India is almost water-tight, between provincial and local roads; and the fact that generally the condition of the former is far superior to that of the latter. This is, I know, a delicate question, but the facts are patent for all to see. Our railways complain, and not without some justification, that commercial motor transport has concentrated on the main Provincial roads, parallel to, or short-circuiting, the railways, in order to share in the traffic already created by the railways, but has neglected short haul transport of goods and passengers on rural roads complementary to the railways, which offers an almost boundless field of extremely useful and lucrative public service. It is notorious that there are other causes, besides the relative condition of the different classes of roads, which have contributed to this development in the past, but it is equally certain that it is the unbalanced state of the road system which has led, in no small measure, to the unbalanced distribution of motor transport. The reasons for the lack of balance are partly financial and partly technical. On the financial side I would only suggest that the tendency all over the world, with the increasing range of road vehicles, is to transfer the financial burden from the locality to a wider area of tax-payers, more thoroughly representing those which use the road. Moreover, the smaller the administrative unit the more does its finance become dependent upon year to year fluctuations of the Monsoon, and the less can regular provision for maintenance be assured. On the technical side (in relation to the administrative aspect) modern road construction is a rapidly developing science, and it is not natural to suppose that the isolated local-board engineer can always have at his disposal the knowledge and experience necessary. He is indeed placed in an unenviable position when deprived of the advice and control of others of wider experience to share his responsibility.

13. The third main reason for the backward state of roads in India I have described generically as technical. But this, I must emphasise, includes the technique not only of road making, but also that of the vehicle that uses the road. No one designs a railway without regard to the type and weight of the locomotives and rolling stock that are to use it, nor is the railway bridge engineer called upon to provide a bridge to carry any load which the locomotive engineer chooses to run over it. But that is very much the position in respect of roads. It is the opinion of this Congress that the unrestricted use of the road by bullock-carts carrying heavy loads on narrow and deformed steel tyres is a source of immense loss to the community, and one of the greater obstacles in the way of the provision of an adequate road system at reasonable cost. That statement we believe to be incontrovertible. The community may prefer this state of affairs to any attempt to remedy it. Our only care is that it should make the choice with its eyes open. The cart itself is, moreover, an extremely inefficient piece of transport machinery, and the Congress has in consequence been endeavouring to focus public attention upon the desirability of conversion of bullock-carts to pneumatic tyres, by presenting modern carts as prizes at shows and in other ways. That, of course, is an immense problem which will not be solved in a few years, but it is in our view deplorable that the arrangement should subsist whereunder the community pays for the roads, and the private individual is free to destroy them without

realising what harm he is doing, and we believe that the question should be thoroughly ventilated.

14. There remain the many technical questions relating to the economical and efficient construction and maintenance of roads, so as to provide a safe and economical service to the community. Here the problems are, firstly, research, and secondly, intelligence. The latter is equally if not more important than the former, because, under the conditions in which most of us work, it is difficult for the individual to keep himself up to date with the progress of knowledge which he should possess. I believe that in the creation of this Congress we have gone a long way in the direction of ensuring the widest possible distribution of available knowledge. There is still a need, I personally believe, for a modern text book of road engineering in India, not only as a basis for the training to be imparted in engineering colleges, but as a constant reference book for the young engineer and even for the older among us who, as years go on, forget parts of our A, B, C. Towards the preparation of such a text book the Congress has made various *sorties*, but it has not so far been possible to find any individual with leisure to do the necessary spade work.

15. Among the objects of research, which is at present being conducted, I may mention that into the property of soils and the possibility of their improvement, being carried on at the Punjab Irrigation Research Institute; and the testing of superior road surfaces which has been commenced on the Test Track at Calcutta. In neither of these has our progress so far been what we would have wished, and I feel that the subjects should be attacked with greater vigour than has been possible in the past. I am frequently asked what practical results I expect to get from soil research. To this question it is not possible to give a definite answer, partly because, if the answer were known, research would not be necessary. It may be that, as a result of this work, we shall regretfully be forced to the conclusion that nothing which the wit of the scientist and the engineer together can devise will enable us to make any substantial improvement to natural earth roads under the wear and tear of medium bullock-cart traffic. I am not myself as pessimistic as that, but I feel that even a definite answer of that nature would give us valuable information, and leave us with three clear alternatives which are (*a*) stagnation, or (*b*) the expenditure of immense sums of money for the construction and maintenance of metalled roads or of less sums for trackways, or (*c*) a widespread revolutionary change in the form of the bullock-cart. But there are other aspects of soil research. Many of our main trunk roads have relatively narrow metalled surfaces, and, with the increase in motor traffic, the loss of life due to accidents arising out of the dangerous state of the earth berms, is appalling. Soil research may help us to improve those berms and to reduce that number of accidents, or it may show us a way to widen the existing metalling at less expense than is now necessary by orthodox methods.

16. On the Test Track at Calcutta we have set ourselves the difficult task of endeavouring gradually to ascertain the most economical type of construction of bituminous or tarred roads under mixed bullock-cart and motor traffic, which is an exceedingly damaging combination.

Our experiments so far have barely touched the fringe of this difficult subject, because we have started with tests of a metalled road, surface treated with tar or bitumen, which, for certain technical reasons into which I need not enter here, is the most difficult specification to test under the Test Track conditions. By the elimination, however, of all variables of climate and traffic, by the accelerated tests which we can undoubtedly get on the Test Track, and by careful quasi-laboratory observation and control, we hope to arrive more quickly at a comparative examination of different specifications, than would be possible by comparing the results on different lengths of open roads, subject to a variety of differences in climate and traffic.

17. I will not, however, weary you with a long catalogue of the various objects of research and experiment, because I think that the necessity is sufficiently obvious. I am, however, convinced that in this matter of research we have been too hesitant. Partly because of the temporary nature of the Road Fund and all that goes with it, and partly owing to other pre-occupations and lack of the necessary organization, we have embarked, I feel, only half-heartedly on a subject which should be dealt with either thoroughly or, possibly, not at all, by a central organization. Whether or not more elaborate central organization should be set up is a question that has to be considered in the future.

18. These are some of the points which, we consider, could usefully be examined by a representative committee, since, without a review of the whole position we feel that a more balanced road system in which the condition of the main roads will be much better than it is, and that of the rural roads will be as good—for their purpose—as that of the main highways, will not be within measurable reach. Looking to the possibilities of the future, I would suggest, as one consideration, the sometimes forgotten canon of public finance that the authority or legislature, responsible for imposing the taxation from which certain revenues are derived, should be responsible for the proper expenditure of those revenues and should not, to the extent which is at present prevalent, give doles to some other authority and wash their hands off the results. This, coupled with the principle that the cost of roads should be distributed between different authorities according to the measure of the interest of each of them, suggests that, ultimately, roads in India will be divided into Central or Federal roads, Provincial roads and Local roads, on the basis of their use. This sub-division of responsibility for roads is now generally practised in Federal constitutions, and, if India were to follow suit, we should in time see a great system of national highways developed and maintained to a uniform standard, in relation to the traffic on the various sections, and independent of the finances of the sometimes not very affluent unit of Government through which the different sections pass. I am aware, Sir, that in the changing constitutional position of recent years, and with the growing challenge to railways of motor transport, the Government of India have had no alternative but to discourage to some extent the use of the Central Road Fund for the development of the main highways, when the regulation of traffic competing with railways on these highways was not only beyond their control, but itself in a somewhat disjointed condition. Now that the machinery of control is in existence,

the danger is less and, while I firmly believe in the imperative necessity of developing roads in rural areas unserved by railways, as a lover of good roads I hope also that the time is coming when money will be more freely available to improve the efficiency, the amenities, and, above all, the safety of the main highways of the country.

19. Sir, I will detain you only a few minutes longer to refer briefly to the work that lies before this meeting. We are to consider the latest report of the sub-committee on soil research and the report of the technical sub-committee dealing with the Test Track at Calcutta (to which I have already referred) and with a host of other matters. We have to consider a proposed classification of roads, which means the evolution of a brief formula of symbols from which the salient features of a road can be seen at a glance. We have also a proposal for a uniform classification or grading of traffic statistics in relation not only to total volume but also to the proportion of different types of vehicle and to unit weights. Such a classification is very necessary in order to enable us to compare on a true basis the performance of different types of road in widely scattered places. We have to consider how far we can afford to continue to give prizes of pneumatic-tyred carts at cattle fairs; and we have an analogous proposal, to consider whether anything can be done to evolve a wheel, less damaging to roads than our steel-tyred enemy, that could be made in the village. The specific proposal for consideration here is that we should offer a prize for the best design. We have also a proposal from Assam to form a local branch of the Congress in that Province, and a number of other questions relating to the management of the Congress.

20. A number of papers, actually 9, have been prepared which would have been read and discussed had the full session been held on this occasion. These have been printed as usual and will be circulated to all members for discussion by correspondence. The Council will make extensive tours of examination of roads in and around Delhi, where there is great variety, graded to the traffic of the different localities, including the finest all-concrete roads, nearly all possible variations of the use of bitumen and tar, trackways, and a demonstration of soil stabilization.

21. I think we can claim, Sir, that we who have the responsibility of providing the roads, by forming ourselves into this Congress, by writing Papers, and by our annual subscriptions which, with a small subsidy from the Government of India, make us self-supporting, have done and are doing all or nearly all that we can to give you the best roads possible for the money available, and to fit ourselves to apply to the best advantage whatever further money may in time have been entrusted to us.

22. Sir, I have kept you long, and it only remains for me to ask you to declare this meeting of the Council open.

Declaring the meeting open Sir Andrew Clow said :—

I share Mr. Mitchell's regret that circumstances make it difficult to secure at present any comprehensive review of road policy for we have now reached a stage when, if conditions had been more auspicious, we might well have paused to take stock of the position and decided how to set our course for the future.

But the demands of the war on our energies are imperative and the situation, with its financial and constitutional uncertainties, is not one in which reliable long-term plans can be prepared. Even in such a matter as road-making in India the war is already playing a big part, and it is a matter for satisfaction that in this sphere the war effort should leave behind it something of lasting value to the community.

If we were able to undertake any comprehensive review of what has been achieved in the last 10 years, we should find ground both for satisfaction and for misgiving. The development of the main road system has been extensive, and it has had big effects on the life and the economy of India.

Mr. Mitchell, who has done so much to lead and inspire this development, can look back on a big achievement. But few will question his appraisement when he refers to the unbalanced state of the road system. This is a subject on which any one who, like myself, is interested in railway traffic touches with diffidence; but it does seem that a disproportionate amount of our resources has gone to developing the main arteries and that the large and virtually undeveloped rural tracts have got rather less than they deserve, and much less than they need.

Mr. Mitchell's analysis of the causes is instructive; I wonder if to the factors he mentions, we should not add another. That is the unduly close connection between road development and the internal combustion engine. There has been a tendency to talk as if the motor vehicle was the only user of the road. We hear constantly of the needs of motor transport but very little of the needs of those who depend on time-honoured means of transport such as the bullock cart and the *ekka*. Can it be that this is because those interested in motor transport are more vocal? They have a press to voice their woes, they form associations, they conduct propaganda, while their rivals on the road are mute. Moreover, as town dwellers they....or might I even say we?....naturally think first of improving facilities between cities and along routes which are already familiar.

But the fact is that the biggest Indian road problems did not start with the introduction of motor transport; they are not even now, in the main, problems of motor transport, and they will not in the future relate solely to motor transport. The villagers needed a good road long before the internal combustion engine was invented; and most of them are waiting for it still.

Even among more modern forms of transport, the motor is not the only one to be considered in planning roads. There is surely a future for the bicycle in India; and the cyclist, whether he carries goods as many do now, or only himself, can be provided with an adequate track at a very small cost. This Congress is helping to restore a sense of proportion by considering questions of bullock cart traffic.

The loud voice of the motor owner tends to make the public think that the problem is one of preventing the bullock cart from spoiling the motorists' road; you, gentlemen, know that it is more a problem of giving an adequate road to the bullock-cart itself. Here there should be an immense future for the pneumatic-tyred cart. I am not sure that I share all Mr. Mitchell's financial views, but I believe that in some areas a loan to make it possible to transform all the carts over a large area would quickly justify itself. It would give an immediate saving in maintenance, and would enable us to develop the countryside at a far smaller cost per mile than is possible at present.

Problems of that character can perhaps be tackled and solved by the orthodox methods of securing funds and applying them. But I doubt myself if the wider problem of rural transport is soluble by such methods. I find it difficult to visualize any loan or tax in money that will supply the countryside with the great network of all-weather roads that it needs. Is it perhaps possible that the solution lies not with any external official agency but with the people themselves?

The capacity of most people in this country to contribute in money towards public work and public welfare is sorely limited, but there are multitudes who could contribute in kind. Here, where we are constantly told that so many have time to spare, road-making would bring quicker results than the spinning-wheel is likely to achieve.

About 70 years ago Ruskin, who was then Professor of Art at Oxford, took his students out to build roads in the surrounding country. England scoffed at the absurdity of the idea; for in this, as in other ideas, he was years ahead of his time. He was trying to teach lessons that we have not yet absorbed fully today—the dignity of labour, the value of using one's hands, the importance of social service and the need of common effort by all classes for all classes of men.

It will be said that any big advance along such lines is hardly possible without a measure of compulsion and that the public at present, would not accept compulsion. I think that is true. Memories of centuries of *begar* remain, and this would seem like a return to the old days when roads, both in India and Europe, were made and maintained by forced labour. But such forced labour was feared and disliked because it was largely imposed by external authority on a limited number of poor men for the benefit of others.

Would there always be the same objection to a free people resolving that all, rich and poor alike, shall give some days of their year to causes of common benefit? Imagination glows at the thought of the bureaucrat

released for a few days from his files for the open road, the business man losing a few superfluous pounds in healthy exertion, the doctor getting an unusual tonic, the journalist writing his sermons in stones, the schoolmaster learning in a new school.

Is this vision of the future merely a fantastic dream, perhaps a nightmare to some ? I am not sure. I am not advocating a policy, for as I have already suggested, this is not practical politics at present and the most enthusiastic advocate of uplift by compulsion will find, when the time comes, that there is a good deal that can be said against it. But it is occasionally profitable to ponder over questions that may arise in the future, and this is one of them.

The people of Europe have long compelled their men to surrender years to the terrible and destructive demands of war. Is it not conceivable that the people of India may yet bind themselves to devote some days to the healthy and constructive needs of peace ?

PAPER No. A — 40.

INTERMEDIATE SCREW PILES FOR THE FOUNDATION OF BRIDGES IN SOFT SOILS

By

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It is common knowledge that, of all branches of Civil Engineering works, the foundation problem, especially that of a bridge in sub-aqueous soil, is most uncertain and consequently it is one which is most difficult to decide with mathematical precision, unlike other structural parts. Considerable literature on the subject has been produced by eminent engineers, all more or less based on personal experience, and though this has definitely helped to formulate methods of solving several practical difficulties met with in construction, one cannot, with any degree of accuracy, even now decide what the behaviour of the particular soil will be for the particular work that is proposed. It is general practice now to take trial borings at the site of a proposed bridge and determine the geology of the soil, basing on which the nature of the foundation is being decided. But even in this case, there are some unknown factors which make the decision very often faulty. The reason is that the action of the boring equipment tends to disturb the underground strata of soil to such an extent that the sample may bear very little resemblance to its normal form at the strata level. However, as a preliminary investigation, this is the only means generally available for preparing designs and estimates. The result of experience in one of the bridge works, where the above statement has been proved, is the subject matter of the present paper which the author hopes will be of some interest to the members.

The bridge in question is situated near Kottayam, Travancore, on a second class unmetalled road which is intended to carry lorries, etc. up to 5 tons or a moderate sized motor or diesel roller. Borings of site of the bridge in question, taken prior to the construction, showed 10 feet loose clay at top and 20 feet ordinary clay below. It was anticipated that stiffer clay would be available further below. On these assumptions and in accordance with the usual practice adopted in such soils at the locality, a bridge with screw piles was designed and the estimate was sanctioned. According to this design, the bridge platform carries a 10 feet roadway resting on rolled steel girders supported over ordinary screw piles, 36 feet long (Figure 1), the soil being known to be clay. The load bearing on each such pile was calculated to be 8 tons and the area of the screw blade was 9½ square feet resulting in a pressure of ·84 ton per square foot. The work was taken up and the piles were screwed down one by one to the estimated depth. It was then noticed that the screwing was very easy and that the piles did not appear to be capable of bearing the requisite load. Therefore, a test load was applied, when each of the piles easily subsided further under an 8-ton load. To find out, therefore,

what load the piles could bear, each pile was loaded with test loads in stages. To begin with, a load of 8 tons was imposed on one of the piles and allowed to remain. An immediate sinkage of 0·10 foot was noticed. A week later, further subsidence of 0·125 foot was observed. A further load of 4 tons was then put on. This gave a further immediate subsidence of 0·10 foot followed a week later by a further 0·125 foot and two weeks later by a further 0·055 foot. The load was then increased to 14 tons. There was no immediate subsidence, but after a week a set of 0·14 foot was observed. The load was left in position and the final total set after 2 months was 0·57 foot. Consequently, the addition of piles at this juncture to lengthen the column and screwing them down to refusal did not seem practicable or profitable as no amount of screwing down further would enable them to bear a greater load. The only other alternative was to abandon the system of screw piles, thus proving that the clay met with was extraordinarily loose and could not be relied on for foundations. A similar experiment was made on another pile which has been screwed down to 30 feet below ground level. This showed similar results but the total set was 0·61 foot. There was, however, nothing to indicate that imposition of a further load would not cause a further set. Instead, however, of abandoning these screw piles, the writer thought of the addition of another larger intermediate blade for each set of the pile thereby trying to see if the increased area of screw surface would not make up the required bearing power of the pile. Accordingly, intermediate cast-iron blades, $4\frac{1}{2}$ feet wide and 2 feet 7 inches in height with flanges on either side (Figure 2), were manufactured in the State Public Works Department Workshops and duly inseited under the top pile and immediately below the ground level, but between two intermediate piles. The whole column was then subjected to screwing with capstans. The result was phenominally satisfactory but gave somewhat varying results. The system of piles went down further to depths varying from 3 to 12 feet but refused to go down any further, owing to the combined resistance of the double screw, one at bottom and the other nearer the top. The capstans used had eight arms with four men on each arm. Thus the combined force of 32 men was found unable to screw down the pile any further and further attempts were stopped. This having been screwed to refusal, was test loaded and each pile was found to withstand a load of 14 tons without any subsidence, thus proving that it will be able to take all ordinary loads which may come over the bridge. The members of this Congress may work up the theory to explain how the system proved successful by the introduction of the intermediate pile. The writer was able to make a satisfactory job out of a very difficult situation and it was thought that it could be copied with profit in similar situations elsewhere.

PAPER No. B—40.

THE FAILURE OF A MULTI-ARCHED MASONRY BRIDGE

By

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Introduction.

All men, including that body of men called engineers live to learn, and even if it is only human to err, the engineer, for one, is never forgiven for any mistake of his, which ultimately costs the tax-payers large sums of money. So it behoves us all to analyse carefully the causes leading to the failure of engineering structures, so that we may guard against the avoidable mistakes and pitfalls in similar constructions elsewhere by utilizing the knowledge gained from past failures. We must review our failures critically in the cold unbiassed attitude of the scientist and we should severely check the natural tendency to cover up our defects, which can only lead to further and probably more costly failures.

In this paper the writer presents the broad details about the failure of an elliptical-arched stone masonry spill-bridge, which occurred about 13 years ago. As usual, the human element about this failure is now very nearly forgotten and it is recorded here as a tribute to the engineers concerned with the reconstruction that they all acted in the best of their beliefs and they spared no pains to save this bridge, that was really not warranted by traffic requirements and should not have been constructed at all and should have been left to its fate when it was severely damaged by the Baitarini flood of 1927.

History of the Bridge.

The river Baitarini (the Styx of Hindu mythology) which rises in the hills forming the western boundary of the feudatory State of Keonjhar, forms for some distance the boundary between British India and the State, and at a point about 66 miles below its source, near the village of Jaintgarh, it is crossed by the main road from Chaibasa (36 miles) to Keonjhargarh (33 miles) which ultimately goes on to Puri (Jagannath) *via* Jajpur Road.

In the year 1912 (after the separation of Bihar and Orissa from Bengal), detailed plans and estimates were called for constructing a high-level bridge across this river by the Government and negotiations somehow led to the States Engineer of the Orissa Feudatory States to be entrusted with the work of preparing the detailed project for this bridge which was submitted by him at the end of 1913. The detailed plans and estimates were sanctioned by the Government in 1915 for the construction of a steel N-girder bridge of 2 spans of 200 feet each (width of roadway 16 feet) and a stone masonry-arched spill-bridge comprising of 30 spans of 30 feet each, (width of roadway 14 feet) forming the northern approach to the main bridge from Chaibasa side. The construction also of the above bridges was carried out by the States Engineer by his own staff and contractors and the bridges were officially opened on March, 5, 1917. The total cost of Rs. 3,23,189 was shared equally between the Government of Bihar and Orissa and the Keonjhar State. By a subsequent agreement, for the proper maintenance of the bridges, the charge of these bridges was made over to the Public Works Department of the Government of Bihar and Orissa on November, 7, 1919. It will be of interest to note here that the roadway over the approach road and the spill-bridge at that time was only gravelled, consolidated with a hand-roller and for want of traffic, grass grew freely over the bridge and its approaches. The traffic preferred the old low level road which was kept sufficiently high and dry.

After the spill-bridge had been taken over by the Public Works Department, an examination of the bridge with reference to the completion plans revealed the fact, that although the foundations of the main girder-bridge pier and abutments had been carried down to rock, the piers of the spill-bridge had been taken down about 9 feet only from ground level and left to rest on clay. Orders were immediately issued by the Chief Engineer for taking borings near the spill-bridge piers, and the results of 8 borings taken in 1920 conclusively proved that clay continued to as low a depth as 35 feet below ground level. No rock was met with even at 40 feet. It was then found from the records that the State Engineer when submitting the estimate for the project in 1913 had given an assurance : "*this bank (northern) is fairly closely underlaid by rock (thus safeguarding the main-bridge abutment and preventing any extensive scour).*" Whether any borings to prove rock were actually taken before the construction of the spill-bridge is not on record. The boring sections clearly showed up the grave potential danger to the structure from possible flood scours, but it appears that it was not considered serious enough, for the then Chief Engineer observed that the spill-channel would not come into operation except in very abnormal floods and that there were reasonable grounds for considering the spill-way quite safe from erosion of its bed. However, he gave strict injunctions "for taking adequate steps should any scour begin to take place", and ordered for a careful annual inspection of the spill-channel. No other safety measures were taken.

Annual inspection reports on the condition of the spill-channel to see whether the main river was tending to develop the spill-channel into the main stream, for the next six years, showed that the spill-bridge stood high and dry and no flood water passed through it, but contrary to expectations, on July, 29, 1927, a phenomenal flood in the river Baitarini dealt a knock-out blow to this bridge all of a sudden. There was a maximum depth of flow of 10 feet through the arches (3 to 4 feet below

springing) and there was heavy scour all around the piers, maximum scour being 10 feet and the average scour 7 feet below bed level. The foundations of the piers of four arches settled, one as much as 1 foot 6 inches and these arches cracked very badly—in one case 3 inches wide right up to the road surface. The bridge parapet walls also got cracked and kinked. Thus the troubles started with an erstwhile safe bridge, and all the subsequent attempts at reconstruction failed and the abandoned bridge stands now as a landmark near the southern boundary of Singhbhum, silhouetted against the background of the distant azure hills of Mayurbhanj.

Geology of the area

In South Singhbhum, the alluvium in the river valleys is underlaid by granitic rocks, in the form of boulders and gravels at varying depths, and higher up, the hill sides are capped with laterite which rests indifferently on metamorphic rocks of the Dharwarian Series and this top-soil is brought down by the rains as the rich red silt in the flood-water. The granitic rocks around Jaintgarh which vary from a basic facies to acid granite, are at most places of the felspathic type which, owing to sericitization by hydrothermal agencies, have led to the formation of large Kaolin deposits.

The presence of Kaolin in the alluvium crust (although very favourable for the growth of bumper crops of rice in this area), has led to the treacherous 'Kewal' formation on which the spill-bridge piers had been unfortunately founded, and which settled and cracked so badly after the flood of 1927. The peculiar nature of the soil demanded special protection of the piers and flooring by adequate curtain walls and pitching which had been overlooked in the original construction.

The River Baitarini

The river Baitarini which rises in the hills on the western boundary of Keonjhar State at an altitude of some 2,750 feet, drains an area of about 700 square miles of fairly densely wooded steep hilly catchment of south Singhbhum and the State above the site of the bridge, and although it presents a practically dry bed during the summer season, like most rivers of Chota Nagpur, during the monsoons it discharges torrential floods charged with huge quantities of reddish silt at high velocities. By its periodical devastation of Orissa and the upland tracts, it has fully justified its name as the River of Hell (Styx). There are records of devastating floods in this river in 1864, 1874, 1896, 1920 and 1927. The flood in 1927 is regarded as phenomenal. This year also, (1940) there has been a heavy flood which caused breaches in the Bengal-Nagpur Railway in Balasore District, and badly damaged the anicut across this river at Akhuapada near the sea.

At the site of the bridge, the river was known to be subject to exceedingly high floods at times, when the flood waters invariably spilled across the line of the original road which was practically level with the country. The importance of this characteristic feature of the river at the bridge site does not appear to have been fully realized in the design of the spill-bridge which is discussed later.

Before the designs for the bridges were taken up by the States Engineer, the Executive Engineer, Public Works Department who was

instructed to co-operate with him in discussing the features of the left bank and their bearing on the bridge project, ascertained from inquiries from the oldest villagers in 1913 that the highest flood level was reached (within living memory) in 1864, when it rained continuously for 13 days. The banks were overtopped and there was a moving sheet of water, a mile wide. The spill took 5 days to subside and there was a fairly strong current.

Only four years before the construction of the bridge, the river spilled across both the banks, and again, during the heavy flood of 1920, the flood rose rapidly to within 20 feet below the girder bridge but there was no erosion of the bed of the spillway which was just reached by the floodwater. But the phenomenal flood of 1927 upset all previous records and calculations, and one of the many structures that were badly damaged is being discussed here.

The Phenomenal Flood of 1927

There had been daily rainfall in the catchment during the preceding week, and it started raining heavily on July, 28, 1927 and on July, 28, 29, at Champua (on the other bank of the river) 22·24 inches of torrential rain fell in 13 hours from 8 A.M. to 9 P.M. That there was intense and widespread rainfall through-out this and adjacent catchments will be clear from the rainfall records (Table A) of the rain-gauge stations near about this area, and it is estimated that the run-off from this thoroughly saturated and fairly steep catchment was of the order of 80 per cent. All the rivers in Singhbhum were in heavy floods and the flood in the Kharkhai put out of action the railway bridge near Jamshedpur which was also flooded in parts by the Subarnarekha.

The villagers living on the side of the hills in Keonjhar State found a vast sheet of water coming down with great velocity, a sight never seen by them before. This vast sheet of water swept away every thing on its way,—cattle, houses, men, all kinds of wild animals, and even elephants into the river Baitarini. In the plains of Orissa, miles below the bridge site, this phenomenal flood-flow was obstructed by the Bengal-Nagpur Railway embankment, the Orissa Trunk Road and the high-level canal embankments which were breached in innumerable places and suffered the heaviest losses ever known. Due to the breaches in the railway embankment between Baitarini Road Station and Kenduapada Road Station, railway traffic on this main Calcutta-Madras route was closed for about two months. This flood in the Baitarini was not only the highest on record but also the swiftest. The rise in the flood level was about a foot per hour whereas usually it is 3 to 4 inches per hour. No data about actual observation of the surface velocity of this phenomenal flood is available but it has been estimated by several authorities as approaching 16 feet per second *i. e.*, about 11 miles per hour.

A thorough analysis of this great flood would reveal, it is believed, many more facts of considerable interest to the engineering profession and it is understood that a memoir on this flood by Prof. Mahalanobis of the Calcutta University will be published shortly.

Table A

RAINFALL RECORDS IN THE BAITARINI AND ADJACENT CATCHMENTS.

Flood of 1927.

Dates........July	20	21	22	23	24	25	26	27	28	29	30	31	Remarks.
1. Anandpur (Keonjhar State) ..	1·50	1·75	0·15	1·66	2·00	0·30	0·63	0·00	0·62	4·97	1·00	0·22	The heavy downpours occurred in the tracks of cyclonic depressions advancing inland from the Bay of Bengal and there were no cloud bursts. It is of interest to note here that the heaviest rainfall recorded in 24 hours anywhere in India is 35 inches at Purnea in Bihar, on September, 13, 1879, but the intensity of the Champua record is evidently higher being 22·24 inches in 13 hours only. This indicates that the intensity might have reached about 4 inches per hour for at least an hour or two.
2. Badampahar ..	..	..	..	..	..	..	..	2·42	9·34	18·12	..	..	
3. Bonaigarh ..	1·13	0·05	1·08	2·85	10·86	1·90	0·85	0·05	0·47	4·66	9·08	0·04	
4. Champua ..	0·00	0·00	2·23	5·25	4·65	1·66	0·08	0·15	1·18	5·68	22·24*	0·00	
5. Gorumahisimi ..	..	..	..	..	..	..	..	3·00	6·50	10·00	..	..	
6. Jagannathpur ..	0·00	0·00	0·56	2·31	4·26	1·79	0·06	0·34	0·36	3·70	11·72*	0·03	
7. Kathbari ..	..	..	0·00	0·00	4·74	1·10	0·00	1·85	6·50	10·46	0·00	..	
8. Keonjhargarh ..	0·27	0·14	0·12	2·34	2·22	0·33	0·32	0·00	0·27	10·50	8·45	0·08	
9. Majhgaon ..	..	..	2·24	7·85	3·00	0·69	0·95	0·25	1·41	4·00	14·04	..	
10. Noamundi ..	..	..	..	..	..	..	..	1·00	3·01	17·85	..	..	
11. Pal-Lahara ..	1·2	0·44	0·75	1·80	5·57	1·40	1·48	0·10	0·67	6·30	5·52	0·03	
12. Sulaipet ..	..	..	..	..	..	..	..	1·38	12·49	15·82	..	..	

Note :—The above represent the rainfall recorded in 24 hours ending at 8 A. M. on the respective dates. Spaces have been left blank where records have not been available.

* Stations within the Catchment of the river above bridge site.

The Design of the Spill-bridge reviewed

The States Engineer who worked out the designs for the main and the spill-bridge across the river Baitarini at Jaintgarh had based all his calculations on a flood discharge assuming a 3/8 inch per hour run-off from the catchment. After having empirically fixed the size of the main bridge as two spans of 200 feet each and allowing for a discharge of 115,900 cusecs at a velocity of 10·66 feet per second, he allowed for the balance of the supposed maximum flood discharge (at only 3/8 inch per hour) to be spilled wholly along the right bank, and calculated that 54,226 cusecs would be discharged through the spillbridge at a velocity of only 3·02 feet per second. In the calculations, the reduction of the water way due to the piers and the effect of the afflux, do not appear to have been taken into consideration.

The outstanding feature about the disposal of spill-water in the design was that no waterway for the fairly heavy spill on the right bank (Plate 7) was provided for, only a 3 feet diameter sluice being allowed under the heavy road embankment, 34 feet high at this point on the State-side. approach. In the report accompanying the original bridge project, it is stated :—

> "The whole of the calculated spill discharge must pass through the spill way on the left bank for the reason that none of it can go through the main bridge, and although there is an initial spill on the right bank, there is no escape, the overflow being headed up and impounded by the main river and therefore rises and falls with it, and a sluice only, therefore, has been inserted through the road embankment at this point, partly with a view hereafter of utilising the impounded water to form a small irrigation tank and partly to drain the impounded water off when requisite."

Before the design of the bridge was taken up, the Public Works Department Engineer had discussed the question of the drainage of the spill-water, (the sectional area of the spill water at High Flood Level was more than twice the area of the main channel and so as not to interfere with the flow he requested for providing sufficient openings on the right bank also. Apparently this suggestion was not considered sufficiently important and was not provided for in the design which forced all the spill-water to be discharged through the thirty arch openings of 30 feet each founded on kewal soil, which were not protected with any curtain walls or aprons to safeguard against probable flood scours.

There is an almost right angle bend in the river about half a mile upstream of the bridge site, (Plate 8) and the low bank on the opposite side, allows the main current of the flood water to spill right across the bank towards the spill bridge which was, therefore, bound to suffer the brunt of any flood attack, on account of its position. That this actually happened was proved by the big breaches in the northern approach road embankment on the Chaibasa side.

The total length of the spill-bridge provided 1,015 feet out of which 29 piers with an average width of 4 feet 3 inches accounted for 123 feet *i.e.*, more than 10 per cent of the waterway.

Elliptical arches (dressed sandstone masonry in lime mortar) were probably preferred to segmental arches with the idea of minimizing

horizontal thrusts and also on architectural considerations and it was, apparently for this reason that abutment-piers had been omitted from the design of this singular multiple-arched bridge. If 3 or 4 abutment-piers had been provided, the work of reconstruction would have been very much simplified and might have lessened considerably the chances of subsequent collapse of more arches.

The pressure on the foundation of the piers worked out to about 1·4 tons per square foot (neglecting the effect of live loads) which was about 2¾ times the allowable pressure of ·55 tons for black cotton (Kewal) soil. In discussing this bridge it has to be remembered, of course, that the nearest railhead when the bridge was constructed, was at Chakradharpur 52 miles away, and at the time of the reconstruction (11 years later) the nearest railhead and post and telegraph office was at Kendposi, 17 miles away and, doubtless, this led to inevitable delays and difficulties in the supply of materials, supervision, and timely inspections. If any responsible officer had got timely information about the flood, he might have rushed to the spot and allowed the flood-water an easier outlet by cutting the road embankment in advance before the flood forced its way through it.

History of the Reconstruction

Immediately after the flood, the Executive Engineer in his comprehensive report, dated August, 6, 1927, on the damages caused to the spill-bridge, emphatically expressed the opinion that the expenses of rebuilding the arches after dismantling the damaged ones, carrying the foundation of the piers to rock, and providing curtain walls, and stone-pitched flooring, would be unjustifiable as there was no guarantee that the bridge would stand another flood of the same intensity. He advocated the adoption of a low-level road to directly connect the main bridge with the road to Chaibasa, abandoning the spill- bridge, and its high approach embankment altogether. A week later, the Superintending Engineer, after his personal inspection held that an expensive work costing over a lac of rupees (Rs. 1,34,266) could not be thus discarded and that further subsequent damages could be guarded against by inserting a row of steel sheet piles driven down to rock level on both sides of the cut waters, scoured portions being filled with heavy boulders and he gave orders for taking a new set of borings pending final decision by the Chief Engineer. Meanwhile the Executive Engineer collected all the necessary data concerning this flood and he calculated the total discharge by Kutter's formula as 9,32,147 cusecs, of which 4,85,341 cusecs passed through the spill-bridge, the velocities in the main stream and the spill-way being calculated as 17·2 feet per second and 8·83 feet per second and the afflux as 6 inches, (the Sub-Divisional Officer had reported this to be 2 feet); and he significantly added that these were theoretical figures and would differ considerably from figures obtained by actual observations during the flood. It may be pointed out here that these figures exceeded very considerably those on which the original design had been based. The result of the three new borings also revealed the presence of brown, and black cotton soil, and very small stone pebbles and sand at a depth of 35 feet (vide plate 6D).

Four months later the Chief Engineer, after an inspection, decided on December 12, 1927 that the cracked arches (Nos. 12, 13, 14 and 15) should be rebuilt after supporting four arches (two on each side of the cracked ones) on timber centerings to take up the unbalanced thrust of the undamaged arches. He expressed the opinion that more waterway for the spill was required and that a causeway which would flow about 3 feet deep maximum should be introduced at the northern end of the approach to the bridge. He also ordered for laying 18 inches of boulder packing on the floor and for putting in curtain walls not less than 15 feet deep both upstream and downstream. He expressed the opinion that the maximum velocity through the arches must have been in the vicinity of 12 to 13 feet per second and the afflux to be about 18 inches. (Later on, the Executive Engineer after observing floodmarks, considered the afflux to be about 1·5 feet which itself would theoretically account for a velocity of about 10 feet per second on the floor of the spill-bridge). The Chief Engineer also decided that the piers of the damaged arches should be rebuilt, taking down the foundation to 15 feet depth.

In the meantime, the Engineer who had designed and constructed the bridge also came on inspection and expressed his opinion that the six masonry arches (Nos. 11 to 16) should be totally dismantled including the pier supports, and piers nos. 10 and 16 should be converted into abutments with foundations carried down sufficiently deep so as to be out of danger, and a clear girder span (about 175 feet long) introduced. He contended that rebuilding the arches would leave the bridge exposed to a future repetition of the disaster. As an additional safeguard, he suggested grading down the Chaibasa approach sufficiently, so that in the event of another catastrophic flood, the water would overtop the bank and carry it away. He also remarked that if the approach embankment had been cut when the flood rose, this simple precaution would have prevented the damage done to the bridge. The Political Agent, in forwarding the above suggestions, expressed his entire agreement with the views stated, and stressed the point that the State should have been consulted in the matter of reconstruction of the bridge and urged that the danger should be removed once for all by the adoption of the new single-span girder proposal, as the road was too important to admit of tinkering with a vital bridge. He also added that the State should not be called upon to pay any part of the cost and that the whole cost of the reconstruction should be borne by the Government.

The Chief Engineer approved of the idea of a breaching section in the bridge approach, but he decided on reconstructing the arches, and restoring the spill-bridge. After personal discussions between the Superintending Engineer and the Chief Engineer, who was not in favour of sandfilling as the correct method of supporting the arches, which was advocated by the Executive Engineer, a compromise was reached on February 9, 1928, and for additional safety it was decided to provide buttresses against piers Nos. 8 and 18 and to fill up with earth the arches proposed to be dismantled. Accordingly arches Nos. 10 and 17 were filled up with sand enclosed between two retaining walls at the two ends of the arch barrel (on February 15, 1928) and as cracks in the arches, especially in No. 12, were observed widening to an alarming extent, arches Nos. 11 and 16 were quickly supported on the previously prepared timber centerings, jacked up from below. Work on the upstream and

down-stream curtain wall foundations to an average depth of 5 feet below the foundation level of the arch piers and 10 feet away from it, proceeded simultaneously and the excavations revealed the thoroughly rotten nature of the Kewal soil which was wholly unsuitable for bearing such a heavy structure.

Although the trenches had been dug so deep near the pier foundations (April 8, 1928), the rubble stones for the curtain wall had not arrived at site and an unexpected fall of heavy rains which resulted in the sides of the trenches to start falling in, revealed at once the real danger affecting the safety of the entire spillbridge. By vigorous efforts, however, the curtain walls were partially completed (at places the excavated trenches had to be filled up again), the walls being brought up to about a foot above the level of the pier foundations.

Simultaneously, work on filling the arches Nos. 12 to 15 completely with earth, prior to dismantlement, had been proceeded with and (by April 27, 1928) the arches Nos. 14, 13 and 12 were dismantled by the contractor (leaving 5 feet on either side of the piers). Two days later, cracks began to develop quickly in arches Nos. 10 and 11. The timber centerings held up the arch No. 11 for sometime. Gradually the vertical posts nearest to arch No. 12 settled; the whole framework of the centering became distorted and after emitting ominous warnings of cracking timber, the whole of arch No. 11 collapsed on April 29, 1928.

On receipt of an urgent telegram the same day, the Superintending Engineer, who was about to go on leave, motored down from Ranchi the next morning. Upon a thorough examination of the situation he found that the props supporting the centering had sunk into the ground thus taking the load off the centering. The horizontal thrust of arch No. 11 on pier No. 11, which was no longer neutralized, because of the dismantling of arch No. 12, pushed the pier resulting in the cracking of the pier about 4 feet from the springing horizontally and shearing of the arch between the cracks, which crumpled up the timber centering inspite of its stout construction of sufficiently heavy sections. He was convinced that such centerings could not provide the full support necessitated by the enormous weight of the arch masonry and earthfill. He, therefore, ordered that arch No. 15 should not be dismantled pending final decision by his successor on revised methods of reconstruction. As he found arch No. 9 intact, he ordered as a temporary expedient, the complete filling-in of span No. 8 with the heavy boulders, then available in large quantities at site, (brought for floor pitching) as he considered that arch No. 9 might crack at any moment and it would be dangerous to allow coolies to work under it. Before he went on leave, he suggested to his officiating Chief Engineer, the necessity for the immediate construction of buttresses in cement mortar against piers Nos. 8, 18 and 19, which had been deferred so long.

The Executive Engineer after his inspection on May 2, 1928 protested against the heavy boulder filling inside arch No. 8 as serious subsidence of the floor and foundation might occur, and he disagreed with the decision on the question of providing buttresses as the foundations necessary for the buttresses dug so close to the existing pier foundations,

might precipitate the collapse of more arches. Again, he urged that good money should not be thrown away after bad and as there was no objection by the respective authorities to the holding up of traffic for a day or two once in about ten years when big floods occurred, he earnestly requested for abandoning the spillbridge and adopting his plans for a low-level road. Almost prophetically, he stated that even if the whole amount of the revised reconstruction estimate of about Rs.1,10,000, were spent in rebuilding the arches with necessary safety precautions, the Public Works Department would not be in a position to guarantee full security for a structure which he considered certain to collapse and he sent a telegram to his Superintending Engineer that further expenditure on the arches was sheer waste of money. The Superintending Engineer instructed him by telegram to relieve the pressure over spans 16, 17 and 19 by removing earthfilling over the arches. Shortly afterwards (on 15-5-28) the new Chief Engineer and Superintending Engineer jointly inspected the condition of the arches at site and issued orders for the immediate construction in cement mortar (1:3) of one buttress on Champua side of pier No. 1 and one buttress on Chaibasa side of pier No. 18, with stone from the dismantled arches and piers. This urgent work was completed (on June 15, 1928) with the greatest care to the satisfaction of the engineers. All this time, slow settlement of arch No. 16 supported on centering continued and it suddenly collapsed. A few days later, after a fall of heavy rain, arch Nos. 14 and 15 collapsed and two weeks later arch No. 10 (which had been filled with sand) also collapsed. (It was at this stage that an interesting fact was brought to light, which was not previously known to the engineers concerned *viz.* that in the original construction of the spillbridge all the arches had been erected on solid centerings, after four arches constructed on timber centerings had failed on account of the unequal settlement of the props). Thereafter, the arch No. 9 collapsed and the arch No. 8 behind the new buttress cracked. When this happened further work on this ill-fated bridge was stopped (on July, 24, 1928) and plans for a low-level road were taken up and the work was completed without any trouble. It is perhaps necessary to add that this road has been admirably serving the traffic requirements of this District and the State without a day's break for the last 12 years and the prophecy of the then Executive Engineer has now been fully substantiated.

Conclusion

After having narrated the history of a bridge failure at some length, the writer feels tempted to thoroughly analyse and test the links in the chain of events that led to it, but is instinctively warned not to theorize too much on "what-might-have-beens". While inviting discussions, which is the main object of the writer, on the variety of problems, both administrative and engineering, raised in this paper he would beg leave to offer suggestion on two vital points which are:—

(1) that the design and construction of costly structures must be left severely alone to recognised experts, who have had sufficient experience in that particular type of work, and who should be allowed the fullest liberty and responsibility for their actions, and

(2) that reconstruction, which are in most cases, very much more difficult than the original constructions, should only be

decided upon after carefully considering the "obsolescence" aspect of the structure, even though a huge sum of money might have been incurred on it, and if reconstruction is decided upon after carefully thinking out the pros and cons of the proposed method of work and its probable effects on the entire structure, changes in the methods should not be allowed except under extremely unavoidable circumstances.

With our present-day knowledge, a submersible bridge with spillways on both the approaches would doubtless have been more economically constructed to suit the requirements of the Baitarini at the site of this bridge; but even so, our conflicting ideas about phenomenal flood discharges and flood velocities, intensities, the duration and the frequency of intense rainfalls and the run-offs from different shapes and sizes of catchment, all point to the absolute necessity for the provision of a fool-proof and automatic arrangement in our costly structures, (on the analogy of the fuseplug and safety valve in boilers and of the fuse and the automatic cut-out in an electrical installation) which would protect the main structure from damages by opening out a path of least resistance to the *forces of Nature like floods, gales or earthquake vibrations* *The writer* had previously developed this idea in his article on "the Design of Road Structures in Seismic Regions," published in "Indian Roads"* and would again urge all engineers to consider seriously this aspect of ensuring the safety of a costly structure by the sacrifice, so to say, of a purposely designed weak link in the chain.

In conclusion, while digressing on the subject of design of bridges, it would perhaps bear repetition to add that in this age of specialization, although it may be conceded that every engineer should be able to design his own work, which he probably can, and by sufficiently increasing his factor of safety to cover the factors of ignorance, his work may stand unless some *important considerations have been inadvertently ignored*, it cannot be denied that it would be safer and more economical to entrust such work to the specialist engineer, who has trained himself to see a mistake instinctively which an average engineer with laborious calculations would surely miss When the specialist, as a result of his experience and mastery over facts and figures can produce at once a suitable and more economic design than others, we would be well-advised to entrust our major bridge problems to specialists in the line, who should be furnished with the necessary data. The want of a representative body of specially trained engineers, skilled in the art of bridge design who could work in a consultative capacity, is keenly felt and it is hoped that the Indian Roads Congress will give a lead in the right direction.

As the writer has purposely refrained from discussing in details the controversial aspect of the design and methods of reconstruction, critically examined in the light of present-day theories and experimental investigations particularly of the new applied Science of Soil Mechanics, not yet generally known or fully understood, he feels that he would be justified in appending a bibliography for the benefit of those readers who would like to go deeper into the problems at issue and put forward their own viewpoints.

*No. XVI, Page 33, Catalogue No. IRO 45 XVI.

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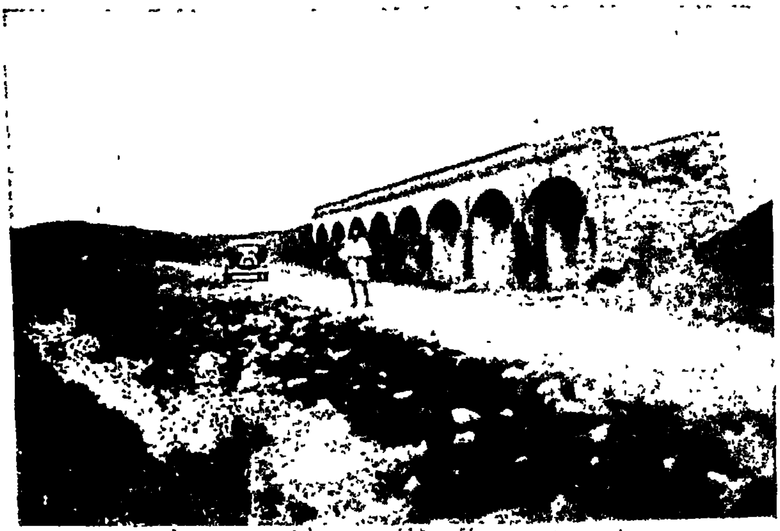
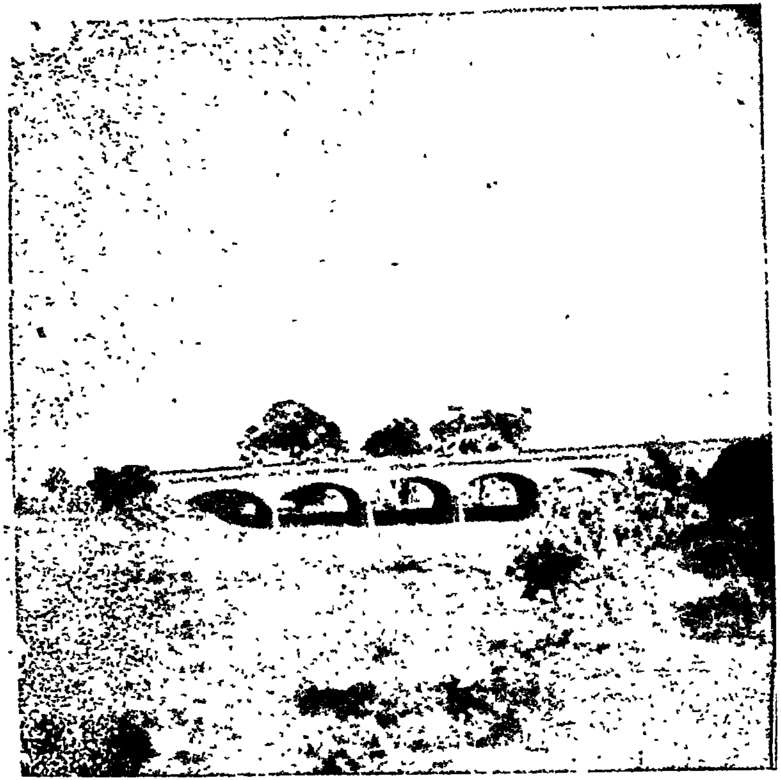
The northern portion of the abandoned Spill-Bridge seen from a distance on the upstream side. (Heavy embankment of the Chaibasa side approach is noticeable.)

PLATE 1.



The Chaibasa side [illegible] now, showing the low level road [illegible]



The southern (Champua) end of the abandoned Spill Bridge, (viewed from downstream side). This is about 400 feet to the north of the main Girder Bridge.

PLATE 1.

Close-up view of arch No. 8 showing buttress built against pier No. 8. This arch cracked after the construction of the buttress.

PLATE 3.

A view of the Baitarini N-Girder Bridge showing the high embankment between the main and Spill Bridge on the right (not within this view).

PLATE 5.

CORRESPONDENCE.

Comments by Mr. P. V. Chance (Central Provinces and Berar).

Mr. Ghose's paper raises questions of great interest to engineers.

The Baitarini bridge is on a main road and its cost was shared between the Provincial Government and Keonjhar State, both of whom considered the expenditure justified. Even after the bridge was damaged in the flood of 1927, the Political Agent pressed for its thorough reconstruction as a vital link on a very important road.

Mr. Ghose states that the bridge should not have been constructed at all as it was not warranted by traffic requirements but surely traffic is not the only consideration. The suitability of the site, the estimated cost of the bridge, and the traffic to be carried, are obviously important factors but they are not the only ones and the eventual decision is seldom based on purely engineering considerations.

Mr. Ghose recommends that, when a bridge is damaged, its "obsolescence aspect" should be considered before it is repaired. But the obsolescence aspect again is a wide one and the engineer is primarily concerned only with the most effective repairs and their cost, leaving the larger question of whether the expenditure is desirable to the authorities who will finance it.

The design was based on the assumption, now known to be wrong, that the spill bridge would be founded on rock. If the State Engineer's report had been correct, this bridge would safely have passed through the phenomenal flood of 1927. Even as constructed, the bridge had passed through the "devastating" flood of 1920 without injury, and the damage in 1927 was, perhaps, less than one thirtieth of the cost of the bridge. I confess, I would have been surprised had the Chief Engineer acquiesced on the proposal to abandon the whole work without making any attempt to repair the small amount of damage and to protect the bridge from further injury.

The Executive Engineer "collected all the necessary data concerning this flood." He calculated the total discharge as 9,32,147 cusecs and he added that the figure was theoretical and would differ considerably from actual observations during flood. I presume this means that he found it impossible to reconcile his calculations with his data and I am not surprised. A flood of 9,32,147 cusecs from a catchment area of 700 square miles corresponds to about 6,800 $M^{\frac{3}{4}}$ and could hardly be correct even for a "River of Hell."

In addition, the Executive Engineer calculated that 4,85,341 cusecs passed through the spill bridge with a velocity of 8.82 feet per second. Now the effective width of the spill bridge is 892 feet and the depth of water, even allowing for a uniform scour of 7 feet throughout the whole length, was not more than 15 feet, so that if 4,85,341 cusecs had passed, the average velocity would be 36 feet per second. The opinion, that the calculated discharges would differ considerably from the actual observations, was, therefore, amply justified and indeed nobody seems to have taken the calculations very seriously even at the time they were made.

The repairs attempted and their failure are the most interesting technical feature of Mr. Ghose's paper but unfortunately the details given are insufficient. Every engineer, who reads the paper, will ask himself "What should have been done? What precautions should be taken and what mistakes should be avoided ? "

Arches 12 to 15 had cracked and were to be dismantled and the Chief Engineer ordered that arches 10, 11, 16 and 17 should be supported on wooden centerings to take up the unbalanced thrust and that buttresses should be constructed against piers 8 to 18. Unfortunately, these orders were changed and, though the Chief Engineer was not in favour of sand-filling as a support for the arches, yet such filling was provided in arches 10 and 17 and only arches 11 and 16 were supported on timber centering and the construction of the buttresses was deferred. There can, I think, be few engineers who will not agree with the Chief Engineer as to the value of sand-filling as a support for such arches.

No adequate particulars of the centering and especially of the footings have been given. The centering held up arch 11 for some time but the posts near arch 12 settled and the props supporting them sank in the ground. The posts were jacked up but the timbers on which the jacks rested must have had insufficient bearing and it is to this detail that the whole failure of the repairs appears to be due. If the wooden centerings had really taken the whole weight of the arches and if they had been used, as originally ordered, in arches 10 and 17 and if the buttresses had been constructed at once, the repairs would very probably have been successful. It would be of great interest if Mr. Ghose could supply full details of the centerings and how they were jacked up to take the weight of the arches.

As I have said, the particulars given are inadequate but the general orders of the Chief Engineer appear to have been suitable if only they had been properly carried out. The tie-ing together of piers 10 and 11, and 15 and 16 would have been an additional precaution. Sand-filling, earth-filling and boulder-filling would be almost useless for relieving the thrust on the piers but would be a safeguard for the workmen. The filling with sand of arches 10 and 17, which the Chief Engineer had ordered to be supported with timber centerings, was unfortunate. The effectiveness of the buttresses could have been improved by increasing the bearing area of the foundations and sloping them so as to throw the weight against the piers. I am not sure why an upstream curtain wall was proposed and I doubt if it would ordinarily be necessary. Otherwise, there appears to be little room for criticism of the orders but much depends on how they were carried out.

There are a few discrepancies in the paper but they are not important. Arch 14 is stated to have been dismantled and subsequently to have collapsed; and a buttress was not, I presume, constructed against pier No. 1.

Mr. Ghose is to be congratulated on a very interesting paper. Papers on failure are always welcome, perhaps this is partly due to the ease with which one can be wise after the event.

Comments by Mr. K. Gupta (Singhbhum, Bihar).

As I have had the opportunity of closely examining the remains of the erstwhile Baitarini spill bridge, which lies within Singhbhum District, I am in a position to corroborate the statement made by Mr. Ghose that the spill bridge "should not have been constructed at all," as the present low-level road alongside the derelict bridge has been functioning all right without any traffic hold-ups since 1927.

Mr. Ghose's Paper raises the vexed question of correctly estimating probable maximum flood discharges of Indian rivers, and it is well-known that no serious attempt has yet been made to collect and scientifically analyse the results of observed data on the major rivers of India. Statistics of maximum intensities of rainfall in different areas in India are also not readily available and the Indian Roads Congress, as a central authoritative body should be able to conduct valuable research on the above lines.*

In this Paper, the author has strongly advocated the necessity for the purposeful provision of a "safety valve" arrangement in structures of considerable magnitude, and the idea is certainly worth further investigations, to evolve practical methods for providing for a "designed weak link in the chain," as this will prevent the numerous wash-outs of bridges that are reported during the flood season every year. In the Singhbhum District, on our District Board roads mostly causeways are provided, and they serve quite well except during torrential floods, which usually subside within 3 to 4 hours. In opening up new lines of communications, causeways should naturally mark the first stage of development. But the spill bridge at Baitarini was really a high-level bridge of unusual design not warranted by the topography of the site.

It would have been interesting if Mr. Ghose had furnished the details of the bridge in the standardised form recommended by the Indian Roads Congress for recording particulars of major bridges. Mr. Ghose deserves to be congratulated as a painstaking historian for delving into the old records and obtaining all the details of the bridge failure thirteen years after the occurrence. The lucid presentation of the facts of the case, after such a long period, reflects great credit on the author, and we are thankful to him for his exhibition of the "skeleton in the cup-board" without prejudice to any one.

Comments by Mr. A. B. Majumdar (Chaibasa, Bihar).

1. The author must be acclaimed as a pioneer in choosing a subject for which though the council expressed the opinion " that there is often great deal more to be learnt from failures than from successes " the contributors of articles have not till our present author, brought to light any paper on such a subject.

*The suggestion to devise a suitable formula for calculating peak discharges of rivers has been engaging the attention of the Indian Roads Congress for some time past. Through the courtesy of the Department of Communications, Government of India, a note on the subject compiled from the information available in the Bureau of Information of the Central Board of Irrigation was obtained and considered by the Technical Sub-committee of the Congress. The Committee considered it impossible to devise a common formula, as many variables are involved. Typed copies of the useful note are now in the Congress Library for reference by members.

2. It must be admitted that the author has very ably got down the facts in details and cleverly refrained from making any suggestions about the controversial aspect of the designing and methods of reconstruction. I hope many useful suggestions will be made in the course of discussion of this thought-provoking paper and we, the younger members of the Congress, will be much benefitted by the facts and suggestions made by the older members from their much valued experience.

3. I will, however, remark that in giving assurance (Page 4, para 2 in italics) the States Engineer never said nor meant that the spill bridge foundations are on rock. He meant the Northern abutment of the girder Bridge. I think borings in this part were not at all taken or the designers were mis-informed and, above all, none of the then Engineers and even the Chief Engineer, Public Works Department did believe that the spill will ever operate which idea permitted carelessness.

4. Providing of openings on the right bank would not have much helped discharge of spill water. From the map on plate 8 of the paper it appears that main flood water will surely go straight across the left bank. Instead of giving any opening in the right bank, a low level causeway at the Chaibasa approach of the spill bridge, to act as a safety valve to the main bridge, with adequate stone pitching and provision of curtain walls to safeguard from scour, seems to me a much better suggestion.

5. The records of the flood of 1927, which the author took so much pains to jot down in this Paper, will evidently be of much help to the future designers of bridges in the vicinity.

Reply of Mr. S. K. Ghose (Author), to the above comments.

It is unfortunate that the paper could not be discussed at an open session of the Congress, so that the various points involved in the reconstruction of the ill-fated spill bridge could be further analysed and compared with similar structures built elsewhere by members from other parts of India. The paper, circulated by post has evoked very little response in the form of written comments, although the writer had intended that the design of spill bridges across rivers draining small hilly catchments should be more fully discussed by the members themselves.

Replying to Mr. Chance's kind comments, it may be stated that only the failure of the spill bridge had been dealt with in the paper. The main steel N-girder bridge (2 spans of 200 feet) was certainly needed for traffic requirements. This was not damaged in any way by the flood of 1927, and is still functioning. The main bridge and the spill bridge were constructed at the same time, and whereas the main-bridge cost about $1\frac{1}{2}$ lakhs, the spill-bridge (30 spans of 30 feet) cost another $1\frac{1}{4}$ lakhs of rupees, and in the opinion of the writer this spill-bridge need not have been constructed at all. Motor traffic between Keonjhar and British India has not been stopped for a single day after the failure of the Spill Bridge It will be interesting to note that this year (1941) also, there was a heavy flood, (about 8 feet below the 1927 high flood level) but traffic was maintained uninterrupted along the low-level road joining the main bridge with the embanked road beyond the derelict spill bridge. The characteristic of the Baitarini is that it rises very rapidly and

also subsides with equal rapidity. It may, however, be added that even now the intensity of traffic on this bridge is rarely more than 2 carts and a truck per hour, which proves that traffic has not yet fully developed in the Keonjhar State (which incidentally, possesses just over a hundred motor vehicles viz: 50 cars, 10 buses, 40 lorries, and 6 motorcycles). It would be difficult to justify an expenditure of roughly $1\frac{1}{4}$ lakhs over the reconstruction of the old spill-bridge which had originally cost the same amount, particularly when it was not possible to guarantee the safety of the structure against another severe flood in view of the inherent defects in the design of the foundations.

Regarding the discharge calculations, in connection with the design of the main and spill bridge (prepared in 1914), the following data from the original records may prove to be interesting.

Locality.	High Flood level.	Cross Sectional Area in square feet.	Wetted perimeter in feet.	Hydraulic mean Depth.
At Bridge site.	84.44	51,289	5,294	9 6
1 mile up-stream.	89.51	85,390	5,150	16.6
2 miles up-stream.	93.41	77,406	5,826	13.3

Mean Hydraulic Mean Depth. $=13.16$

Slope of surface $=8.97$ *feet in 2 miles or* $S=.00085$

From Kutter's formula $V=C\sqrt{RS}$

$$=67.6\times\sqrt{13.16}\times .00085$$
$$=7.15 \text{ feet per second.}$$

Now the designer has taken the mean of the three sectional areas and multiplied it by the above velocity and arrived at

$$D=71,362\times 7.15$$
$$=5,10,237 \text{ cusecs.} \quad \text{(I)}$$

According to Dickens' Formula

$$D=CM^{\frac{3}{4}}=1000\times 703^{\frac{3}{4}}=1,36,526 \text{ cusecs.} \quad \text{(II)}$$

Discharge on the basis of a 3/8" run-off

$$=3/8\times\frac{1}{12}\times\frac{5280^2}{60\times 60}\times 703=1,70,126 \text{ cusecs.} \quad \text{(III)}$$

The designer has discarded the discharge figure arrived at from the Kutter's formula as absurd; and accepted the discharge figure on the basis of a 3/8" run-off. Then he calculated the discharge through the main bridge channel as 1,15,900 cusecs (10,872 square feet *multiplied by*

10.7 feet-velocity calculated by Kutter's formula). Deducting this from 1,70,126 cusecs, he arrived at the balance of 54,226 cusecs as the spill discharge. Dividing this by the spill area of 17,909 square feet he deduced the velocity in the spill channel as 3.02 feet only.

It will be noticed that the designer has, possibly due to inaccurate data and observations of the Baitarini, calculated the discharges and the velocities as even less than those obtained in ordinary floods in this river. After the failure of the spill bridge in 1927, the Executive Engineer, worked out the total discharge by Kutter's formula as 9,32,147 cusecs out of which he apportioned 4,85,341 cusecs as passing through the spill bridge, the velocities in the main stream and spillway being worked out by him as 17.2 feet and 8.8 feet respectively. Evidently Kutter's formula has been used without much importance being given to the coefficient of rugosity, and the calculated figures are not borne out by later flood observations. The problem of calculating spill discharges requires further investigations by engineers in India.*

From a comparison of the above results, and also bearing in mind the record fall of rain of 22.24 inches in 13 hours on the 30th July, 1927 at Champua near the bridge site (which gives an average intensity of about 1.7 inches per hour), it will not be difficult to realize how grossly the discharge and velocity factors had been under-estimated in the original design.

On the question of centerings, the enquiries made by the writer from the contractor's agent and the overseer on the job, revealed the fact that the centering timbers were not adequately or rigidly counterbraced, and the concentrated pressure of the lifting jacks contributed to the unequal settlement of the yielding *Kewal* soil. It appears that no proper sole plates had been provided under the jacks for distributing the pressure from the props.

One point about the paper may perhaps be emphasized here, *viz.* that all the facts and figures contained therein, were collected thirteen years after the event, mostly from old records, and from investigations at site, and from persons who were directly connected with the work. If some inaccuracies have crept in the paper, the writer will be too glad to stand corrected.

The author is grateful for the helpful comments made by Mr. Gupta, and would urge the Congress to institute further researches on the maximum flood discharges of Indian rivers.* Since the work of Lille, Hearn, Glass and Granville, not much systematic work appears to have been done and the importance of Flood-Hydrographs is still not fully realized by some engineers.

While agreeing generally with his remarks about the usefulness of causeways as the first stage in the development of a road system, the writer would point out the classical case of the causeway over the Kharkhai, on the important road between Ranchi and Jamshedpur, which effectively stopped all traffic continuously for five days during the present rainy season, when about 8 feet of water passed over the road level. A high level bridge would not have cost very much more, and traffic would not have been stopped after every heavy continuous shower in the catchment. Low level causeways are so many positive obstructions on

* *vide* footnote on page 14c.

important lines of communications, and the traffic hold-up on the Lilajan causeway and Sone causeway on the Grand Trunk Road would not be tolerated in other countries even under peacetime conditions.

The writer believes that if only engineers would take the trouble to analyse the defects in the design and construction of all existing bridges with the critical eyes of a research worker, more useful work would be done than could be achieved by a soul-less tabular statement on bridges in different parts of India. However, the compilation of a comprehensive statement on bridges in India is considered to be a step in the right direction, and all should help.

A quotation from the records will perhaps serve to clear the doubt of Mr. Majumdar about the designer's idea regarding the spill bridge foundations. When submitting the estimate for the project he gave an assurance that "rock was underlying the surface of the ground at no great distance and that the pier foundations for the spillway would be carried down to rock." He reported in 1914 that borings to prove this were being taken but the results of these borings were never submitted to Government. Mr. Majumdar is right when he thinks that the States Engineer took it for granted that the pier foundations would be founded on rock, although in the actual execution of the work, this was not attended to. In Bridge Engineering, no data should be taken for granted, and it is a safe maxim for all bridge engineers to spend some money on borings so as to ensure that the bridge would be built on sure foundations, instead of trying to salvage a jerry-built one, when Nature has dealt it a knock-out blow, after finding out its weak spots sooner than we imagine.

The writer does not agree with the remark of Mr. Majumdar that the provision of additional waterway on the right bank would not have helped the discharge of the flood water. An examination of the cross-sections and a little calculation about the discharge figures would prove that the waterway provided was totally inadequate to cope with a phenomenal flood of the unbelievable magnitude experienced in 1927. It is for this reason that the writer will continue to advocate the application of the principle of "safety valve" construction in all our costly structures, which should be designed to last only for a reasonable life of usefulness, in view of the rapid changes in design and construction methods being evolved to fit in with the New Order in the field of Engineering as in other walks of Life.

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PAPER No. C—40

TRANSITION CURVES FOR ROADS

BY

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FOREWORD

Before proceeding with this paper, the author wishes to acknowledge with very many thanks the encouragement and help given by Mr. W. B. McLauchin, A.M.I.C.E., late of Gammons Ltd., Bombay. His assistance in simplifying and co-ordinating the various formulae into a form suitable for reconstructing into graphs was invaluable.

The author also acknowledges with many thanks the valuable assistance given by Sri R. N. Padhi, Student Engineer under him (the author), who performed most of the troublesome and tedious task of calculating and plotting values for the various Graphs. Without his help, this paper could never have been written.

INTRODUCTION

This paper does not lay any claim to the discovery of any new principles. But it does attempt to simplify and reduce to assimilable form the latest principles for the design of transition curves on the basis of a rational mathematical analysis which have been accepted and enforced in England, America and Australia. These have been enumerated at great length in Professor F. G. Royal Dawson's two books on the subject, "Curve Design" and "Road Curves."

These books, however, and also other existing specifications on the subject, appear to have been written for engineers with a fairly advanced knowledge of mathematics fresh in their minds, or for men who specialise only on roads. The average assistant engineer or even executive engineer in India who has a varied assortment of accounts, correspondence, canal, and building work to cope with, in addition to his road work, would seldom have the time or inclination to study these principles, or if he did, would find it almost impossible to explain their working, as given in the accepted books, to the average overseer, without whose assistance in the field, no appreciable number of transition curves could be laid out. It was this problem of evolving an easy practical method of laying out transitions which the average overseer could grasp, which the author has attempted to solve in this paper.

The method adopted has been to reduce the numerous and complicated formulae on the subject to a few easily read graphs, thus leaving the overseer or engineer with practically nothing to calculate and very little

room to make mistakes. As a check on his work, he would have to use only the simple formula (No. 13) for apex distance, involving only the use of ordinary secant tables.

The method of laying out transition curves advocated by Professor Royal Dawson and other authorities, involves, in all cases, besides the use of complicated tables and formulae, the use of a theodolite. This is essential because, by the use of deflection angles, the preliminary calculations for the curves are slightly simplified, provided the formulae and methods are properly grasped. As the average Public Works Department Sub-division in India has only about one theodolite for the use of three or four road overseers, this alone precludes their methods from the sphere of common place engineering. These methods have, therefore, not been considered at all in this paper. Instead of this, the very much more complicated formulae required by the offset method of laying out spiral transition curves, which Professor Royal Dawson abandons because they are so cumbersome, have been graphed and are thus made perfectly simple.

By using these graphs, the only instruments required in the field, after measuring the deflection angle between the two tangents with a sextant or prismatic compass, are a chain and tape.

GENERAL.

Transition curves of more or less arbitrary design have been in use for a long time in the layout of Railway tracks, but it is only in recent years that their use has been extended to roads, or that the principles of their design have been analysed from a rational and mathematical standpoint. A transition curve in a road is, briefly, a curve so shaped as to follow the natural path of a fast moving vehicle as it leaves the straight and commences to move in a segment of a circle. With the old horse-drawn vehicle, the speed was so slow that it could switch off almost directly from the straight line to the curve,—often of small radius. With modern fast motor traffic, with speeds increasing every day and often higher than on railways, this is impossible. A gradual change in direction,—how gradual is determined by the skill and speed at which the motorist is able to turn his steering wheel with safety,—is inevitable. As most of the old existing roads which were originally constructed for horse drawn traffic, have not been designed for this gradual change in direction from the straight tangent line to the circular arc of given radius, it follows that fast traffic must deviate from the centre line of their own traffic lane to make their own transition. Examples of such manouvering are explained in detail further on. The only alternative which would allow a driver to turn almost directly from the straight to the curve would be to slow down to a speed considerably below the natural safe speed for that curve. Very few, if any, drivers do this. Consequently no road laid out as a circular arc can be described as a "good fit" for the traffic using it. It is obvious that such deviations of vehicles from their own traffic lane in order to take a corner are dangerous, and become more dangerous every day as the number of fast motor vehicles on roads increases. It has been proved in practice, by subsequently transitioning a bad corner where accidents were of habitual occurrence, that the number of accidents was considerably lessened after the corner had been properly transitioned. With the number and speed of fast motor traffic increasing rapidly, it is the duty of every engineer, by correct design, to attempt to lessen the

proportion of accidents on his roads. This general introduction to the subject of transition curves may appear unnecessarily long, but it is inserted in the hope that it may make at least those engineers more "transition minded" who, while admitting the principle in theory, are content to assume that, with the exception perhaps of extreme cases, there is ample margin in the width of the ordinary road to cover the discrepancy between the road alignment and the actual track of the vehicle, so that they see no need for improvement.

It is also hoped that the very simplified methods detailed below will make others "transition minded" who have been, as I was, frightened off the correct method of dealing with the problem by the complicated formulae and methods advocated in recent engineering periodicals and text books on the subject. It requires only half an hour's study of the graphs and summary of procedure attached to enable any overseer to understand the method of working out the required data, and once this is done, it becomes as easy to lay out a transition curve as a circular arc.

GENERAL PRINCIPLES

When an object such as a motor car is constrained to move in a curve, it has an acceleration towards the centre of $f = \frac{v^2}{R}$

To impart an acceleration to any body force must be used. The amount of the force $P = \frac{Wf}{g}$ where P is the force

W = the mass of the body in pounds.

f = acceleration in feet per second.

In the case of a car moving round a curve, the force pulling it towards the centre is, therefore $P = \frac{Wv^2}{gR}$

This force is, in practice, supplied by means of the front steering wheels of the car through the medium of friction and the propelling force of the engine. The steering wheels of the car divert the propelling force of the engine from a forward direction to a sideways direction, *i.e.*, towards the centre of the curve by means of the grip the car wheels have on the road.

If the car wheels have not sufficient grip on the road this force will not be strong enough to cause the required $\frac{Wv^2}{gR}$ to pull it round in a curve and the car will 'skid' or shoot off in a straight line tangential to the curve at the point where the skid occurs.

As this grip on the road or force is caused by the friction, it follows that the friction between the car wheels and the road must be equal to or more than the centrifugal force.

The force of friction between any two objects is given by the formula $F = B\,W$

where B is the coefficient of friction between the two objects and W = the weight of the object resolved at right angles to the plane of contact.

The coefficient of friction between rubber tyred vehicles and the average road surface may be taken as $\frac{1}{4}$.

The force of friction on a non-super-elevated road then becomes $F=\frac{1}{4}W$.

This must be equal to or more than the centrifugal force

$$F=\tfrac{1}{4}W \geq \frac{Wv^2}{gR}$$

i. e. $\quad \frac{1}{4} \geq \frac{v^2}{gR}$

where $\quad g=32$ approximately

and $\quad v$ is in feet per second.

This resolves itself on simplification to $\frac{V^2}{14 \cdot 97R} \leq \frac{1}{4}$ where V is in miles per hour.

Or a general simple formula taking $14 \cdot 97=15$

$$V^2 \leq 15BR=15\times\tfrac{1}{4}R \ldots\ldots\ldots\ldots (1)$$

or

$$V^2 \leq 3 \cdot 75R \ldots\ldots\ldots\ldots\ldots\ldots (1)\ A$$

This fixes the relation between the permissible speed and the radius of a curve (or vice versa) *on a non-super-elevated curve.* The amount of friction called into use automatically adjusts itself to the speed, becoming greater as the force becomes greater, till the velocity, V, reaches the limit when the centrifugal force exceeds friction and a skid results.

Super-elevation is usually provided on a curve to introduce a factor of safety against sliding or skidding. It could, theoretically, be provided to eliminate the necessity of friction entirely but as the centrifugal force for a fixed radius depends on the velocity, it would be necessary for all vehicles then to move round the curve at the speed for which that curve was designed. Owing to the different types of traffic varying from bullock carts to fast moving cars, this would obviously be impossible.

It can be shown that the theoretical super-elevation of a road which would be essential if there were no friction is given by the formula $\tan \alpha = \frac{V^2}{15R}$ where V is in miles per hour and α (see figure 1) is the angle of cross-fall of the road with the horizontal.

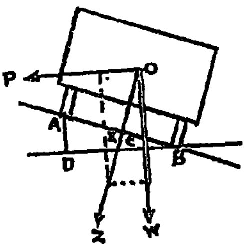

Fig. 1

As this is not practicable in design, it is not proposed to go into the derivation of this formula.

A theoretically correct super-elevation can therefore, seldom be given. The most that

can be attempted is to provide a slight super-elevation based on practical consideration which will tend to reduce the amount of friction brought into play, and thus provide a factor of safety against the limiting speeds calculated from the friction formula (1) above.

The super-elevation allowed in the current Circle specifications in Orissa is quite suitable from a practical point of view and is reproduced below.

ORISSA CIRCLE TABLE FOR SUPER-ELEVATION

Radius in feet.	Super-elevation to be adopted (percentage of width) = 100 e.	Cross Slope.	Increase in width for road width of 9 feet = w.	Remarks.
				This works out theoretically correct for speeds given below, assuming no friction *This is not to be taken into account for design*
30	16·6	1:6	4·5	6·65 m p h
50	12·5	1:8	4·5	9·7
100	12·5	1:8	4·5	13·6
150	10·4	1:9·6	4·3	15·3
200	10·4	1:9·6	4·1	17·7
300	9·4	1:11·6	3·7	20·3
400	9·4	1:11·6	3·3	23·7
500	8·4	1:12	2·9	25·1
600	8·4	1:12	2·5	27·4
700	6·2	1:16	1·7	25·8
800	6·2	1:16	1·7	27·3
900	4·2	1:24	1·3	23·7
1000	4·2	1:24	0·9	25

Most countries, however, allow a more or less fixed super-elevation of 10 per cent for curves of all radii. This is shown in the table on page 32 of the "Summary of Procedure" attached to this paper. The maximum figure of from 10 per cent to 16·6 per cent is arrived at from a consideration of maximum cross slope which can be allowed in a road so that the hooves of animals pulling slow vehicles will not slip.

TRANSITION CURVES

When a car is moving along the straight, it has no acceleration towards the centre or sideways (since there is no centre). When it comes on to a curve it has an acceleration of $\frac{V^2}{15R}$ towards the centre (V being in miles per hour).

This acceleration produces a considerable force which is transferred by means of friction through the wheels of a car and through the springs to the super-carriage.

If this force is applied suddenly, *i. e.* if the car, by means of an exceedingly quick turn of the steering wheel, moves directly from the straight path on to the curve, it can be proved by dynamics that momentarily a force equal to double this force acts on the car.

In the case of aeroplanes which "bank" or turn at a very much higher speed, often reaching 400 miles per hour, this force has a more especial significance. For at such a high speed, the force, known in aeronautical circles as "*G*", becomes so large that a pilot cannot stand it and becomes unconscious till the turn is completed. The maximum amount of "*G*" which a man can stand without "blacking out" is about 8 times the force of gravity and the radius of turning of high speed aeroplanes has to be restricted so that this will not be exceeded.

A transition curve on a road is therefore introduced

(a) in order to minimise this force,

(b) in order to give the driver time to turn his steering wheel round to adjust it to the shape of the curve, and

(c) to avoid discomfort to passengers due to the fact that they would otherwise suddenly be shot towards the centre at a fairly considerable acceleration.

To take the last reason first, it has been found that a change of acceleration of between 1 and 2 feet per second per second per second is un-noticeable or at least is not uncomfortable. The figure for the permissible rate of change of acceleration will be denoted by "*C*." Assuming therefore, that it takes T seconds for a car to traverse the full length of the transition curve, the rate of change of acceleration from zero to f is equal to $\frac{f}{T} = C$.

But $f = \frac{v^2}{R}$ (v in feet per second)

$\therefore$ Rate of change of centrifugal acceleration

$$= C = \frac{v^2}{RT}$$

Now the time T taken for a vehicle to traverse a transition of length L is given by the equation $T = \dfrac{L}{v}$

Hence $C = \dfrac{v^2}{R} \div \dfrac{L}{v}$

$= \dfrac{v^3}{R\,L}$ (where v is in feet per second)

or reducing v to miles per hour

$$C = \frac{3{\cdot}155\, V^3}{R\,L} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2)}$$

This must not be greater than the permissible rate of change of acceleration which will pass un-noticed.

The American practice is to take the figure for C to be 2 feet per second per second per second and the English practice, 1 feet per second per second per second. The American practice will be adopted because it is sufficiently safe and gives transitions half the length which would be permissible if English practice were followed, thus allowing a greater latitude when dealing with S bends which are often essential for economic reasons.

The Australian practice (Victoria Country Roads Board) is to allow a figure of 2 feet per second per second per second for C up to 50 miles per hour and a figure of for 1·536 per second per second per second for speeds above 50 miles per hour.

This is very sound in theory, as it is obvious that in high speeds, a motorist is not able to turn as fast as in low speeds, but it introduces much complication into the calculations for transition curves, which for the average P. W. D. staff are already complicated enough. And as speeds of above 50 miles per hour are seldom likely to occur in practice in India due to the necessity for caution when negotiating bullock carts and pedestrians with an insufficiently developed road sense, it is proposed to keep to a fixed value of $C = 2$ for all speeds.

It has been observed that the maximum which skilled racing motorists, by a sudden turn of the steering wheel, can attain is a rate of change of acceleration of 3 feet per second per second per second, but obviously this is too high a figure to allow for C for the design of roads meant for the average driver.

This brings us to the second reason why transition curves are introduced,—to give the driver time to swing his steering wheel round from that required for a straight path to that required for a curve of radius R. It is obvious that however quick and expert he may be, it must take some measure of time for him to swing his wheel round. During this time, the radius at which the car is moving gradually lessens from infinity (the radius of a straight line) to R, the radius of the curve. Any moving vehicle MUST, therefore, follow a transition curve. A transition is a curve with a gradually decreasing radius which is designed to follow the path which a car is automatically made to take by a gradual turning of the steering wheel.

It may be argued that most roads upto date are not provided with any transitions and can yet be traversed at anything between 20 and 50 miles per hour. The reason is that all cars make their own transitions by leaving the centre of their carriage way and "cutting in" or otherwise manouvering at curves as described below.

Take for example, a quite usual curve of 290 feet radius and a 72 degree deflection angle, and consider the behaviour of motorists who enter it. These may be roughly divided into three groups.

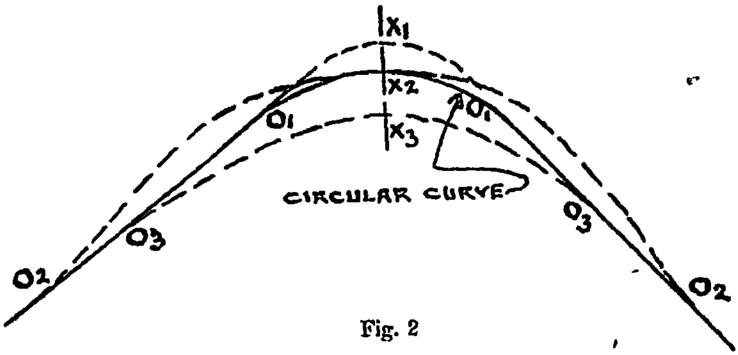

Fig. 2

(1) Motorists who for various reasons may not be aware of the curve till they have entered it. The natural trend of such vehicles is shown as O_1X_1 in figure 2. The tendency to diverge to the left would, if not corrected by a sudden pulling to the right and a sharp application of brakes amount to about 20 feet at the centre of the curve. This would, of course, be disastrous on one of our ordinary trunk roads.

(2) Motorists who see the curve in advance and endeavour to adapt themselves to it as closely as possible. In this case the natural transition begins at O_2 and by means of a slight S bend gets about 3 or 4 feet to the left of the centre line and then cuts into the curve at X_2. This usually involves a slight slackening of speed.

(3) Motorists who notice the curve in advance and have time to see whether there is room on the berm to "cut the corner" and thus make a proper transition with the necessary amount of shift as shown in the line $O_3 X_3$. In this case they would have to commence leaving the centre of the road about 100 feet before the actual commencement of the curve and would travel any distance up to 6 or 7 feet on the inner side of the centre line while on the curve.

It is obvious that a road curve should be designed to obviate the necessity for any of this manouvering away from the centre of the carriage way especially where traffic is heavy and the motorist is likely to meet another vehicle manouvering in the same way from the opposite direction.

DERIVATION OF FORMULAE :- To obtain the required length of a transition curve, combine equations (1) and (2) on pages 4 and 7 respectively

From (1) $V^2 = 15\, B\, R$.

$$\therefore \quad V^3 = 15^{3/2} \times B^{3/2} \times R^{3/2}$$

Substitute for V^3 in equation (2)

$$C = 3{\cdot}155 \; \frac{15^{3/2} \times B^{3/2} \times R^{3/2}}{R\,L}$$

$$\therefore \quad L = 182{\cdot}5 \; \frac{B^{3/2} \sqrt{R}}{C}$$

Substituting the values of the constants $B = \frac{1}{4}$ and $C = 2$ in this equation

$L = 11{\cdot}5\sqrt{R}$ = length of transition........................(3)

From equation (1), it is seen that the permissible velocity increases as R increases, and equation (3) allows for an increase in length of the transition to correspond with the increased radius and velocity. We would thus get very long transitions increasing up to infinity for curves of large radius if the safe speed were increased indefinitely. This is clearly quite unnecessary. A limiting speed may, therefore, be fixed for a particular road and any curves with a radius larger than the safe radius for that speed will be safe up to that speed.

Having decided on this speed, the radius for which can be calculated from equation (1), $V^2 = 15\, B\, R = 15 \times \frac{1}{4} R$, the lengths of transition may be calculated direct from equation (2).

A Graph has been drawn out accordingly for the lengths of transitions, assuming a maximum speed of 60 miles per hour (See Graph No. 1.)

In this graph the limiting radius for a maximum speed of 60 miles per hour is given by substituting in equation (1).

$60^2 = 15 \times \frac{1}{4} R$

$R = 960$ feet.

From 960 feet radius onwards the length of transition is calculated from equation (2), V being constant and equal to 60

$$C = 2 = \frac{3{\cdot}155 \times 60^3}{R\,L}$$

$$i.e.\ L = \frac{3{\cdot}155 \times 60^3}{2} \times \frac{1}{R}$$

$$\therefore L = \frac{340740}{R} \quad \text{.......................................} \quad (4)$$

Thus after 960 feet radius, L gets shorter as the radius increases. This can be seen clearly from the graph.

Shape of Transition :—It has been explained that the chief function of a transition is to provide a curve whose radius gradually decreases as the length increases till such point as its radius merges into the designed radius of the curve.

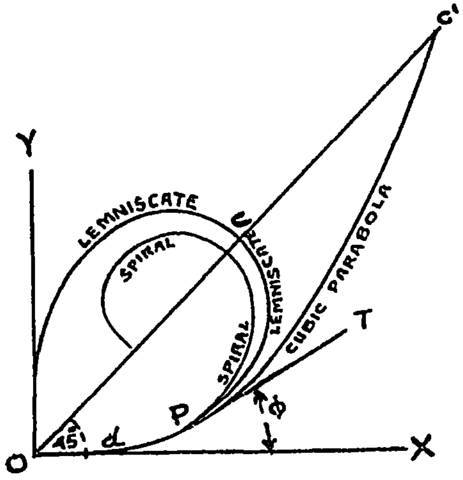

Fig. 3

The ideal curve is the true spiral whose equation is $l = m\sqrt{\phi}$ .. .. (a) l being the length of curve from the origin at any point P, measured along the curve.

m is a constant for the particular curve and ϕ is the angle in radian measure between the tangent at any point P and the x-ordinate.

By differentiating in the formula $l = m\sqrt{\phi}$

$$\frac{d\,l}{d\,\phi} = \tfrac{1}{2}\, m\, \phi^{\left(\frac{1}{2}-1\right)} = \frac{m}{2\sqrt{\phi}}$$

But $\dfrac{d\,l}{d\,\phi} = \dfrac{\text{a small change in length}}{\text{a small change in angle}}$

$= r$ where r is the radius of the curve at the point

$$\therefore r = \frac{m}{2\sqrt{\phi}}$$

$$\therefore m = 2\,r\sqrt{\phi}$$

Multiply both sides by m

Then $m^2 = 2\,r\,(m\sqrt{\phi}) = 2\,r\,l$

$$\therefore \quad m = \sqrt{2\,r\,l}.$$

Hence as m is constant, rl is also constant. r is therefore, inversely proportional to l, thus fulfilling the essential function of the ideal transition.

Substituting for m in equation (a)

$$l = \sqrt{2\,r\,l\,\phi} \text{ or } l = 2\,\phi\,r$$

$$\therefore \quad \phi = \frac{l}{2\,r} \quad \text{.......................................(5)}$$

ϕ being in radians (not degrees).

In order to devise a convenient method of laying out transitions in the field, we want to reduce this to cartesian co-ordinates.

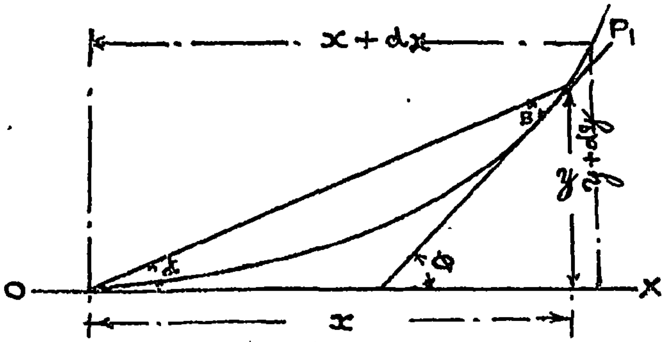

Fig. 4

We have therefore $dy = dL \sin \psi = \frac{m \sin \psi \, d\psi}{2\sqrt{\psi}}$

and $dx = dL \cos \psi$

By expanding $\sin \psi$ and integrating we get

$$y = m\sqrt{\psi}\left(\frac{\psi}{3} - \frac{\psi^3}{7\times\lfloor 3} + \frac{\psi^5}{11\times\lfloor 5} - \frac{\psi^7}{15\times\lfloor 7} + \cdots\cdots\right)\cdots\cdots (b)$$

(The author is indebted to Professor Royal Dawson for the working out of the above formula *vide* "Curve Design" p. 39).

Substituting $\frac{l}{2r}$ for ψ from equation (5) and taking the final value of $l = L$, the full length of the transition, and $r = R$, the final radius (or the radius of the circular curve), this formula gives the value of the final Y or the ordinate at the end of the transition as under

$$Y = \sqrt{2}\,R\,L\sqrt{\frac{L}{2R}}\left\{\frac{L}{2R\times 3} - \left(\frac{L}{2R}\right)^3 \cdot \frac{1}{7\times\lfloor 3} + \left(\frac{L}{2R}\right)^5 \times \frac{1}{11\times\lfloor 5}\cdots\right\}\cdots (c)$$

Substituting $11{\cdot}5\sqrt{R}$ [(from equation (3)] for L up to 960 feet radius

$$Y = 11{\cdot}5\sqrt{R}\left\{\frac{5{\cdot}75}{\sqrt{R}}\times\frac{1}{3} - \left(\frac{5{\cdot}75}{\sqrt{R}}\right)^3\times\frac{1}{7\times\lfloor 3} + \left(\frac{5{\cdot}75}{\sqrt{R}}\right)^5\times\frac{1}{11\times\lfloor 5}\cdots\right\}\cdots(6)$$

This may also be expressed in the form

$$y = \frac{l^3}{6RL} - \frac{l^7}{336\,(RL)^3}$$

which is sufficiently accurate for all values of R and L, l being the length from the origin at any point P along the curve. Above 960 feet radius keeping to a fixed velocity of 60 miles per hour $L = \frac{340740}{R}$ from (4)

$$\therefore \quad \frac{L}{2R} = \frac{340740}{R\times 2R} = \frac{170370}{R^2} \text{ from (4)},$$

$$\therefore \; Y = \frac{340740}{R}\left\{\frac{170370}{R^2}\times\frac{1}{3} - \left(\frac{170370}{R^2}\right)^3\times\frac{1}{7\times\lfloor 3} + \left(\frac{170370}{R^2}\right)^5\times\frac{1}{11\times\lfloor 5}\cdots\right\}\cdots\cdots\cdots\cdots(7)$$

These are troublesome formulae to work out, but as they are essential, the value of Y for various values of R has been calculated and plotted on Graph No. 1. The scale for Y is given on the right hand side.

Similarly by expanding cos ϕ and integrating

$$x = m\sqrt{\phi}\left(1 - \frac{\phi^2}{5\times\underline{|2}} + \frac{\phi^4}{6\times\underline{|4}} - \frac{\phi^6}{13\times\underline{|6}} + \dots\dots\dots\right) \dots\dots\dots (d)$$

Substituting $m\sqrt{\phi} = L = 11{\cdot}5\sqrt{R}$ up to a radius of 960 feet or 60 miles per hour and $\phi = \frac{L}{2R} = \frac{11{\cdot}5\sqrt{R}}{2R} = \frac{5{\cdot}75}{\sqrt{R}}$ we have

$$X = 11{\cdot}5\sqrt{R}\left\{1 - \left(\frac{5{\cdot}75}{\sqrt{R}}\right)^2 \times \frac{1}{5\times\underline{|2}} + \left(\frac{5{\cdot}75}{\sqrt{R}}\right)^4 \times \frac{1}{9\times\underline{|4}} - \dots\dots\dots\right\} \dots (8)$$

This may also be expressed in the form

$$x = l - \frac{l^5}{40(RL)^2} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (8)A$$

which is sufficiently accurate for all values of R and L.

Above 960 feet or 60 miles per hour

substitute $m\sqrt{\phi} = L = \frac{340740}{R}$

and $\phi = \frac{L}{2R} = \frac{170370}{R^2}$

$$X = \frac{340740}{R}\left\{1 - \left(\frac{170370}{R^4}\right)^2 \times \frac{1}{5\times\underline{|2}} + \left(\frac{170370}{R^4}\right)^4 \times \frac{1}{9\times\underline{|4}} \dots\dots\right\} \dots\dots (9)$$

Values of X and Y according to the equations 7 and 8 have been plotted for various values of R in graph No. (1). The scale for X is given on the left hand side.

Approximate Formulae:— Going back to the general formula for y (No. b) and substituting l for $m\sqrt{\phi}$ and $\frac{l}{2r}$ for ϕ we have

$$y = l\left\{\frac{l}{2r}\times\frac{1}{3} - \left(\frac{l}{2r}\right)^3 \times \frac{1}{7\times\underline{|3}} + \left(\frac{l}{2r}\right)^5 \times \frac{1}{11\times\underline{|5}} \dots\dots\dots\dots\dots\dots\right\}$$

For small values of ϕ the second and subsequent terms are so small as to be negligible and $y = l\left(\frac{l}{2r}\times\frac{1}{3}\right) = \frac{l^2}{6r} = \frac{l^3}{6rl}$

But rl is a constant and equals $\frac{m^2}{2}$

$\therefore \quad rl = RL$

$$\therefore \quad y = \frac{l^3}{6RL} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (10)$$

This is the formula for the cubic spiral. Taking a further approximation for small angles *i. e.* that $\lambda = l$ we get the formula for the cubic parabola $y = \frac{x^3}{6RL}$ ....(11)

For most transitions designed according to the principles enumerated above, these approximate formulae No. 10 and 11 are sufficiently accurate for all practical purposes for plotting x and y for curves of over 300 feet radius, right upto the final value of x and y at the end of the transition.

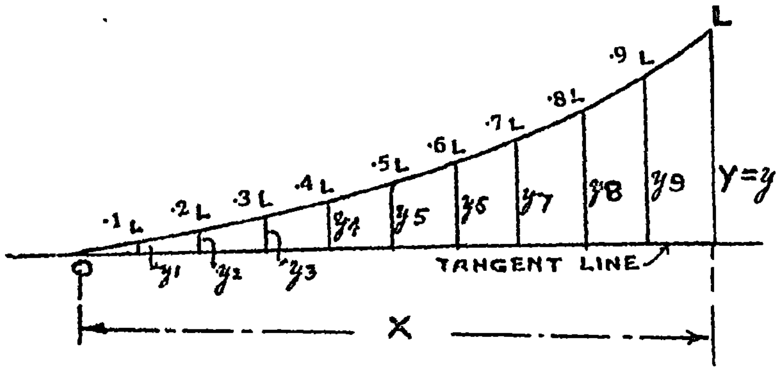

Fig. 5

For radii less than 300 feet, they will also be sufficiently accurate for the commencement of the curve at least, where the angle ϕ has not attained its full value and where x approximately equals l. For curves under 300 feet radius, however, an error of 3 or 4 feet will be found in the final value of x and y.

If however, the final value of X and Y be plotted in the field from the accurate formulae Nos. (6), (7), (8) and (9) and the intermediate values of x and y derived from the approximate formula No. (10), the error not being accumulative will be small. By actually laying out curves in this manner, it has been found that the error in the centre line does not amount to more than 6 inches. For all practical purposes, this is negligible for road work.

TRANSITION CURVE

We now have a simple method of laying out a transition curve by means of equal chords and offsets. This is an adaptation of the method shown in page 51 of "Curve Design" by Professor Royal Dawson, but avoids the accumulative inaccuracies which would normally be considerable in curves of small radii.

Suppose the length L be divided into say 10 equal chords, the length of each chord will be $\cdot 1L = l$, as in figure 5.

From formula No. (10) $y=\frac{l^3}{6RL}$

$$y_1=\frac{(\cdot 1L)^3}{6RL}=\frac{(\cdot 1)^3L^2}{6R}=\cdot 1^3Y \text{ from formula.......(10)}$$

Similarly
$$\begin{aligned}
y_2 &= (\cdot 2)^3\, Y = \cdot 008Y\\
y_3 &= (\cdot 3)^3\, Y = \cdot 027Y\\
y_4 &= (\cdot 4)^3\, Y = \cdot 064Y\\
y_5 &= (\cdot 5)^3\, Y = \cdot 125Y = \tfrac{1}{2}\text{ shift.}\\
y_6 &= (\cdot 6)^3\, Y = \cdot 216Y\\
y_7 &= (\cdot 7)^3\, Y = \cdot 343Y\\
y_8 &= (\cdot 8)^3\, Y = \cdot 512Y\\
y_9 &= (\cdot 9)^3\, Y = \cdot 729Y\\
y_{10} &= (1\cdot 0)^3\, Y = Y.
\end{aligned}$$

The final X and the final Y can be read off graph No. 1 and the intermediate chord points plotted according to the above table taking care in the case of curves of radius smaller than 300 feet that the chords of length $\frac{L}{10}$, are measured along the curve and not along the X ordinate or tangent, and that the offsets y_1, y_2, y_3 etc., are measured at right angles to the X ordinate, see figure 11.

OTHER FORMULAE :—The following formulae are also necessary to enable transition and circular curves to be laid out.

Tangent Distance :—

Tangent distance (see figure 9) = $AO=AC+OC$

$$AC=(R+S)\tan\frac{\Delta}{2}$$

$$OC=OB-BC=X-DZ=X-R\sin\phi$$

$$T=AO=(R+S)\tan\frac{\Delta}{2}+X-R\sin\phi$$

But $\phi=\frac{L}{2R}$ *vide* formula (5)

$$\therefore\quad AO=(R+S)\tan\frac{\Delta}{2}+X-R\sin\left(\frac{L}{2R}\right)\ \text{..........(12)}$$

$\left(\frac{L}{2R}\right)$ being in radians.

This formula may also be resolved into the following form

$$T=(R+S)\tan\frac{\Delta}{2}+\frac{L}{2}-\frac{L^3}{240R^2}\ \text{........................(12) A}$$

In this formula $\frac{L^3}{240 R^2}$ is negligible above 300 feet radius. Hence for radii above 300 feet $T=(R+S)\ \tan\frac{\Delta}{2}+\frac{L}{2}$ .... (12) B

These formulae have been worked out and plotted for various intersection angles and radii in GRAPH No. 2.

For small tangent angles *i.e.* where R is greater than 300 feet $\text{Sin}\psi=\psi$ very approximately

$$i.e.\ \text{Sin}\left(\frac{L}{2R}\right)=\frac{L}{2R}$$

$$\therefore \qquad OC=X-R\ \text{Sin}\frac{L}{2R}$$

$$=X-R\times\frac{L}{2R}$$

$$=X-\frac{X}{2}=\frac{X}{2}$$

i.e. the transition length lies half on the straight and half along the circular curve as it would have existed before fitting in transitions

This is a very useful point to remember, especially when filling in transitions on curves in existing roads.

Apex Distance:— $=A=AX$ (see figure 9.)

$$=AM-X_1M=(R+S)\sec\frac{\Delta}{2}-R \ \ldots\ldots (13)$$

Shift:— (S) $=XX_1$ (see fig. 9)

$$=CD-DE=CD-(ME-DM)$$

$$=CD-(R-R\cos\psi)$$

$$=BZ-R(1-\cos\psi)$$

$$=Y-R(1-\cos\psi)\ldots\ldots\ldots\ldots\ldots\ldots(14)$$

ψ being in radians and equal to $\frac{L}{2R}$, shift can be calculated accordingly.

This may also be reduced to the form

$$S=\frac{L^2}{24R}-\frac{L^4}{2688R^3} \quad \ldots\ldots\ldots\ldots\ldots\ldots (14)A$$

These are accurate formulae for shift and have been plotted in GRAPH No. (1).

An approximate formula which is sufficiently accurate for curves of over 300 feet radius is worked out below :—

Shift $=XX_1=CD-DE$

DE is the versine or middle ordinate of half chord, DZ.

$$DE \times 2R = DZ^2$$

$$DE = \frac{DZ^2}{2R} = \frac{\left(\frac{L}{2}\right)^2}{2R} \text{ very approximately } = \frac{L^2}{8R}$$

$$CD = Y = \frac{L^3}{6RL} \text{ from formula (10) } = \frac{L^2}{6R}$$

$$\therefore \quad S = \frac{L^2}{6R} - \frac{L^2}{8R} = \frac{L^2}{24R} = \frac{Y}{4} \quad \ldots\ldots\ldots\ldots (14)$$

Circular Arc:— (Fig.9)

$=$ Distance ZZ_1 measured along the curve

$=R\,(\Delta - 2\phi_1) \ldots\ldots\ldots\ldots (15)$

where Δ and ϕ are both expressed in radians,

ϕ is known from formula (5)

$$\phi_1 = \frac{L}{2R} \text{ from equation (5)}$$

Expressing Δ and ϕ in degrees this formula works out to

$$ZX_1Z_1 = \frac{\pi R d^\circ}{180} - L \ldots\ldots\ldots\ldots (16)$$

d being the intersection angle DAO_1 in degrees.

This brings us to a very important point in the design of curves.

This expression may be equal to zero, in which case the two transitions OZ and OZ_1 meet in centre, X_1, having a radius $=R$ at that point, but they must not become a negative quantity, which would mean that the two transitions would overlap in the centre, and there would be a sharp angle at point X_1, instead of a smooth curve as sketched below.

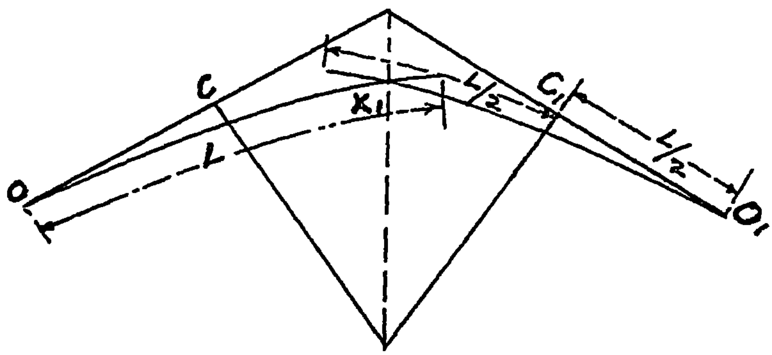

Fig. 6

Putting it mathematically, it follows from equation (14) A that L must not be greater than $\frac{\pi R d^\circ}{180^\circ}$..................................(16) A.

If we take it that CB, the length of transition on each side of point C, is equal to $\frac{L}{2}$ then the total length of transition curve inside the previous circular arc $= 2 \times \frac{L}{2} = L$.

And the length of circular arc before transitionary being $\frac{\pi R d^\circ}{180^\circ}$, it is self-evident from figure (9) that L must not be greater than $\frac{\pi R d^\circ}{180^\circ}$.

The value of the expression $\frac{\pi R d}{180}$ depends on two factors, d and R. d is fixed for any particular curve. It follows therefore, that if the expression $\frac{\pi R d}{180}$ is less than L the only way to make it bigger is to increase the radius R. *This* MUST *be done if correct transition curves are to be provided.*

If it is desired to use the various formulae given above for designing transition curves it is important that these two expressions, L and $\frac{\pi R d}{180}$ be worked out and compared in every case. But if the graphs attached to this paper are used, it will be self-evident from graph No. 2 that the Radius chosen is impossible because the graphs showing tangent distances are non-existant for such impossible cases. The graph also enables the lowest radius which will allow correct transitions which meet at the centre, without having any intermediate circular arc, to be chosen at a glance. Such transitions will be found along line PQU in Graph No. 2.

The formulae for apex distance, shift, and length of circular arc are not strictly necessary for laying out a transition curve on a new road, as the transitions can be laid out by calculating only L, T, X, Y, x, and y, thus fixing the points Z and Z_1 (*vide* fig. 9). The circular curve can then be laid out in the field by connecting up points Z and Z_1 by a circular curve worked out on the versine formula described further on. The apex distance, shift and length of circular curve are thus found automatically without calculating.

But having laid them out on the field, it is an extremely useful and, in fact, an essential check on work to check up the actual lengths of A and Z and Z_1, as found in the field, with the calculated or graph values.

The formula or graph for the apex distance is also very useful during a preliminary reconnaissance to find out approximately where the centre of the curve will come in the field, with a view to avoiding very low land, rock out-crops, buildings, or other obstructions.

The formulae for shift and apex distance are also especially useful for laying out and checking up at site whether proper transitioning is feasible in an existing circular curve on an old road which it is desired to improve.

The guiding factor when trying to introduce a transition into an existing circular curve on a road is whether the shift involved brings the edge of the road beyond the inside edge of the earthen flank or into a building or other obstruction. The graph for shift shows that the shift is practically constant at 5·25 feet upto 960 feet radius and decreases gradually thereafter. It is quite easy to remember this figure of approximately 5 feet for shift and decide at a glance at site whether a transition can be conveniently effected.

Layout of Circular Curve :—An apology is due for introducing elementary formulae for circular curves into this paper, but as the paper is written as much for overseers, many of whom may be quite new to road work, as for engineers the method of layout is described so that the whole procedure from beginning to end may be as fool-proof as possible.

The method recommended is that known as the versine method as this is the least liable to mistakes.

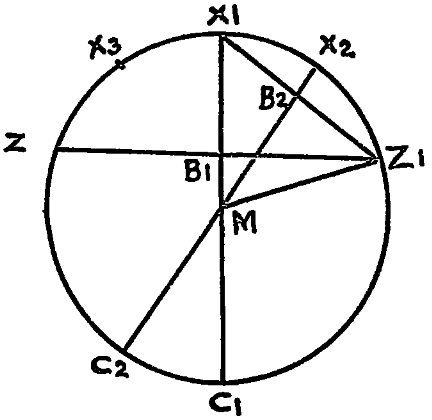

Fig. 7

It is desired to fill in a circular curve of radius R between points Z and Z_1. (Fig. 7)

Join $Z\ Z_1$.

Let B_1 and X_1 be the centre points of the chord and arc respectively.

B_1X_1 is known as the versine or middle ordinate of the segment of the circle, $ZX_1\ Z_1$, and is generally known as λ.

By Geometry

$$X_1B_1 \times B_1C_1 = ZB_1 \times Z_1B_1$$

$$B_1C_1 = C_1X_1 - B_1X_1 = 2R - B_1X_1$$

$$ZB_1 = B_1Z_1$$

$$\therefore\quad X_1B_1(2R - X_1B_1) = ZB_1{}^2 = \frac{ZZ_1{}^2}{4}$$

$$i.e.\ \lambda(2R - \lambda) = \frac{ZZ_1{}^2}{4}$$

$$2R\lambda = \lambda^2 + \frac{\text{chord}^2}{4} \qquad \ldots\ldots\ldots\ldots\ldots \text{(17)}$$

λ should be calculated from this formula when the angle ZMZ_1 is fairly large. But as this is very seldom the case the following approximate formula is usually used.

When angle ZMZ_1 $(\Delta - 2\phi)$ is small (say less than 45°) λ is very small and λ^2 may therefore be neglected. The equation becomes $2R\lambda = \frac{\text{chord}^2}{4}$

$$\therefore \quad \lambda = \frac{\text{chord}^2}{8R} \text{ approximately} \quad \ldots\ldots\ldots\ldots\ldots (18)$$

For this formula $(\Delta - 2\psi)$ must not be greater than 45 degrees. Expressing this in degrees, $\left(d^\circ - \frac{L}{R} \right) \times \frac{180}{\pi}$ must not be greater than 45°.

The point X_1 having been found and plotted in the field as described above, intermediate points X_2 and X_3 can be similarly plotted, for similarly. $X_2B_2 = \frac{X_1Z_1^2}{8R}$. (see figures 7 and 12).

The process may be repeated as often as desired to obtain points on the curve which are close enough. Usually points X_1, X_2, X_3, etc., 25 feet apart are quite accurate enough.

This versine method is a convenient and almost universally adopted method of ascertaining the radius of an old existing curve, as the points $Z_1X_1Z_2$ and B_1 are apparently easily located from the centre line of the existing road.

But in practice, it is found that very many overseers or surveyors and many Subdivisional Officers make a mistake in that they almost invariably, until taught, take points Z and Z_1 along the centre line of the *straight tangents instead of on the curve portion.*

On calculating from this wrong data, the radius obtained is necessarily larger than that which actually exists. This is shown in the sketch below:—

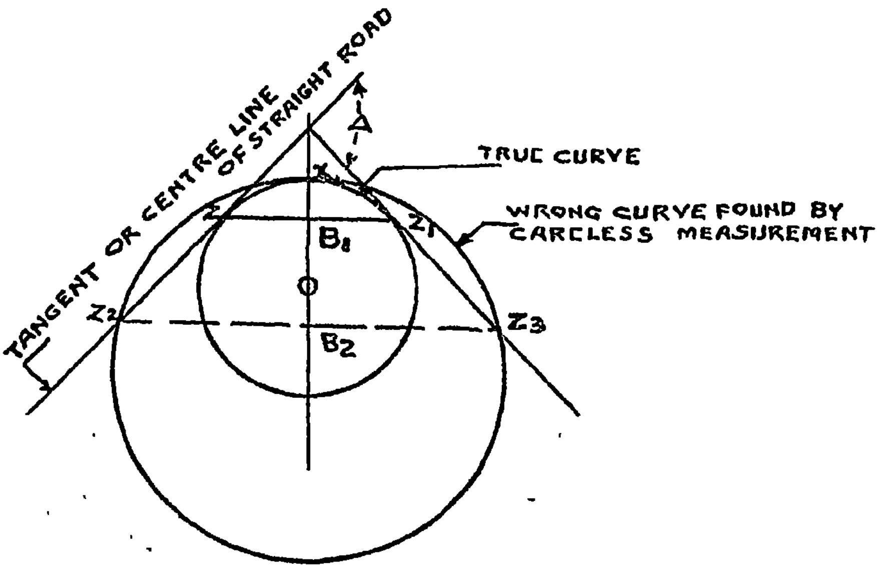

Fig. 8

This sketch is of course exaggerated, but it is self-evident that if the chord points are taken at $Z_2 Z_3$ along the tangents instead of at Z and Z_1 the radius so calculated will be much larger than it actually is.

It is, of course, impossible to fix the exact points where the tangent touches the circle by eye at the site. It is therefore always best to take the points $Z\ Z_1$ well inside the circular arc to avoid a mistake in the opposite direction.

To be on the safe side, it is also well to insist on all Overseers or Surveyors who are deputed to collect field data on curves to submit their calculations for radius along with a scale dimensioned drawing of the circular arc showing chord and versine lengths as well as the deviation angle, Δ. Any mistakes in field observations will become apparent when an attempt is made to draw the curve to scale.

These precautions, though elementary, are essential to enable a correct design for transitions to be worked out as it is the initial plan showing the radius and deflection angle of the existing curve on which all further calculations have to be based. It is surprising what absurd results can be produced by inexperienced Overseers if not carefully instructed and watched.

"S" CURVES.

S curves are merely a combination of two circular curves see figure 10 and present no real difficulty. But care has to be taken when designing them that the curves do not overlap in the middle.

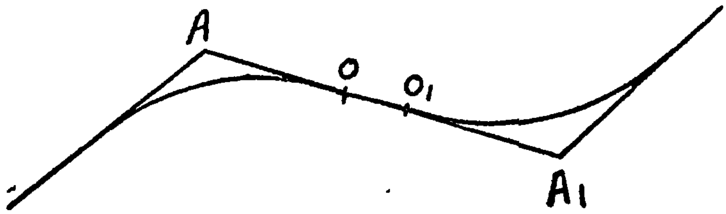

Fig. 10

If the sum of the two tangent distances for the two curves $A\ O + A_1\ O_1$ exceeds the distance between apex points, $A\ A_1$, the curves will overlap in the middle. To avoid this, either the radii would have to be decreased or the apex points, A and A_1 would have to be shifted further apart.

"HAIRPIN" BENDS.

These are merely cases where the deflection angle, Δ, equals 180 degrees. The difficulty in treatment lies in the fact that the tangent distance becomes infinity, and there is no apex or starting point from which the normal procedure could commence. This can easily be overcome by a very little trial and error on a scale drawing. With a pre-determined radius, X and Y can be ascertained from the graphs and plotted on paper. A circular arc can then be plotted between two ends of the transition.

The distance from the apex to the origin of the transitions can be scaled off and the laying out in the field then follows the usual procedure.

COMPOUND CURVES are unidirectional circular arcs of different radii with a common tangent point. These are difficult to transition properly, and, as a sudden decrease in radius after the curve has been entered is most disconcerting to a driver, they should be avoided at all costs.

VERTICAL CURVES.

Just as a change in direction in a horizontal plane causes discomfort and stresses in a car, so also a change of direction in a vertical plane causes similar inconvenience. It is not proposed to investigate such changes from a mathematical standpoint, as the correctness of the preliminary assumptions made in such mathematical analysis by recent authors has not been sufficiently established. But for practical purposes, the standard laid down by the Country Roads Board, Victoria, Australia serves as an excellent guide and is reproduced below. Figures are also given to show the allowance required for sufficient visibility over a "hump" or change in grade, so that a car can brake in sufficient time after viewing the oncoming car. They allow for an average co-efficient of friction in braking of $F = 0{\cdot}50$ and a "reaction time" of 0·5 seconds between the time when the oncoming vehicle is first sighted and the moment when the mind and muscles react and press the brakes.

Speed (Miles per Hour).	Minimum sight Distance in Feet on Centre Line at 4 Feet Above Road Level.
30	175
35	225
40	275
45	335
50	400
60	550
70	750

For comfort, the rate of change of grade should not exceed the following values.

	Speed (Miles per Hour)						
	30	35	40	45	50	60	70
Maximum rate of change of grade (per cent) in 100 feet.	16	12	9	7·5	6	4	3

The recommendations of the Indian Roads Congress allow for a fixed sight distance of about 550 feet, which agrees with the figures given by the Country Roads Board, Victoria for a speed standard of 60 miles per hour. It is not possible to design all roads, especially in hilly country, for this speed standard. Hence where local conditions demand a greater latitude, the Victoria Roads Board specifications are recommended.

The recommendations of the Indian Roads Congress (vide appendix II, Vol. V of the Proceedings) are reproduced below:—

"In the case of vertical curves the maximum gradient should be 1/30 used over a horizontal distance not exceeding 200 feet, and the rate of change of gradient should not exceed 1/100 per hundred feet measured horizontally, and the summit of the curve should be made horizontal for a distance of 100 feet. A sight distance of about 550 feet will be thus automatically provided."

It is necessary that particular attention be paid to design of grades according to the above figures in approaches to culverts or bridges along a straight road where the section speed is high.

SECTION SPEED.

In designing a section of a road in an area with generally uniform topographical character, endeavour should be made to provide for all curves one and the same speed (known as the "Section Speed") thus affording uniform driving conditions and safety over the Section. At the end of the section where there is a change in the topography, and it is necessary to change from one Section Speed to another, it is desirable to change the speed on successive curves in steps of 5 or 10 miles an hour, so as to accustom the driver gradually to changing conditions. Where on an exceptional curve, the speed has to be reduced below the Section Speed, a warning sign should be provided, especially for large abrupt changes in driving conditions, *e. g.*, a reduction of 20 miles per hour or more below the Section Speed, but such isolated curves below the Section Speed should be avoided whenever they can be eliminated.

Standard notation for transition curves (Reference Figs. 9, 11, 12 and 13.)

$C\,X\,C_1$ = circular curve before laying out transition.

OZ_1 & O_1Z_1 = transition curves or spiral curves.

ZX_1Z_1 = portion of circular curve remaining after filling in transitions.

O = point of change from tangent to spiral.

Z = point of change from spiral to circle.

L = total length of transition spiral from O to Z measured along the curve (in feet).

l = length in feet from O along the spiral to any point on the spiral.

v = designed speed in feet per second.

V = designed speed in miles per hour.

Δ = intersection angle DAO_1 in radians = angle CMC_1.

d = angle DAO_1 in degrees = angle CMC_1.

R = radius in feet of circular arc CXC_1 before transitioning = radius of circular arc ZX_1Z_1 after transitioning = minimum permissible radius of spiral at X_1 assuming that the two spirals meet at the centre and that there is no circular curve.

$x,y,$ = abscissa and ordinate, respectively, of any point on the spiral with reference to point O as origin and OA as the X ordinate.

X, Y = coordinates of Z :— $X = OB$:— $Y = ZB$.

ψ_L = angle ZTA = tangent angle = angle made by the tangent to the spiral at point Z with the X ordinate.

ψ = angle made by the tangent to the spiral with the ordinate at any point P.

S = shift = distance between the positions of the circular curve before and after transitioning.

T = total tangent distance = $A\,O$ = AO_1.

A = AX = total external secant or apex distance.

B = permissible coefficient of friction between wheels and road = $\frac{1}{4}$.

C = permissible rate of change of acceleration per second per second per second:— Assumed 2 for all speeds.

λ_1 = $X_1\,B_1$ = versine or middle ordinate of segment ZX_1Z_1.

λ_2 = $X_2\,B_2$ = versine or middle ordinate of segment $X_1\,X_2\,Z_1$.

e = the super-elevation expressed as a decimal fraction of the metalled width of the road.

E = total super-elevation in feet for Radius R.

c = usual road camber or cross-fall in straight road expressed as a fraction of the half width *e.g.* 1:36, 1:48 etc.

w = increase in road width.

W = original road-width.

SUMMARY OF FORMULAE AND METHOD OF PROCEDURE FOR DESIGN AND LAYOUT OF TRANSITION CURVES.

(REFERENCES GIVEN TO FIG. 9, 11 & 12.)

Serial No of Procedure.	Description of procedure.	Number of graph to be used.	Alternative formulae which may be used in absence of graph.	Formula No.
1.	RADIUS = R. Decide on the speed standard to be adopted, and find out corresponding value of Radius (R) for this speed standard. Any radius larger than this R may be adopted. Speed standards for hill roads may be less (below 35 m.p.h.) than for plains roads (above 35 m.p.h.). Change in speed standard and radii to be effected gradually say 60, 50, 45, 40, 35, 30, 25, 20 etc. Maximum speed assumed 60 m.p.h.	FOR ALL RADII. Graph No. (1) V. Read value of radius in feet against corresponding value of speed in m p.h on the two horizontal scales.	BELOW 60 m.p.h. $V^2 = 3{\cdot}75\ R$ .. .. V in m.p.h. R in feet ABOVE 60 m.p.h. The radius may be anything above 960 feet.	(1) A
2.	LENGTH OF TRANSITION = L. Find length of transition curve "L".	FOR ALL RADII. Read L from graph No. 1 (L). Scale for L on the left hand side.	BELOW 960 feet Radius $L = 11{\cdot}5\ \sqrt{R}$ .. .. ABOVE 960 ft Radius, $L = \dfrac{340740}{R}$	(3) (4)
3.	DEFLECTION ANGLE = Δ Fix deflection or intersection angle d = angle DAO_1 Angle DAO_1 = d in degrees = Δ in radians)	This is fixed from the road alignment and may be checked off from the plan for new roads, or actually measured by means of a prismatic compass or theodolite in the field.		

Serial No. of Procedure.	Description of Procedure.	Number of Graph to be used.	Alternative formulae which may be used in absence of Graphs.	Formula No.
4.	OVERLAPPING TRANSITIONS. Verify if radius selected is too small to allow correct transitions with the deflection angle required (which is fixed). If so, a larger radius should be selected to prevent transitions overlapping. Work out new transition length for this new radius *vide* procedure (2).	FOR ALL RADII. Graph No. (2). Read Δ, and R. If R comes below line PQU, the transitions overlap. A higher radius on or above this line must be selected. Points on this line, PQU, give radii which allow no intermediate circular curve	Verify if L is greater than $\frac{\pi Rd^o}{180^o}$ .... If L is greater than $\frac{\pi Rd^o}{180}$, calculate minimum R by equating $L = \frac{\pi R d}{180}$ .... Always remember to calculate L from formula (3) below 960 feet radius and from formula (4) above 960 feet radius.	(16)A (16)
5.	TANGENT LENGTH = T Find tangent length $AO = T$, R and d^o being fixed.	FOR ALL RADII. Graph No. (2) Read T in feet on vertical scale on the LEFT.	0 to 300 feet RADIUS. $T = (R+S)\tan\frac{\Delta}{2} + X - R\sin\frac{L}{2R}$ .. where S is calculated from formula (14) Y is calculated from formula (6) or (6) A X is calculated from formula (8) or (9) A L is calculated from formula (3) Alternative Formulae 0 to 300 feet radius $T = (R+S)\tan\frac{\Delta}{2} + \frac{L}{2} - \frac{L^2}{240R^2}$	(12) (12)A

Serial No. of Procedure.	Description of Procedure.	Number of graph to be used.	Alternative formulae which may be used in absence of graphs.	Formula No.
	. . . .	. .	Where S is given from formula, (14) or (14) C and R is given from formula, No. (3). 300 feet to 960 feet RADIUS. $T = (R+S) \tan \frac{\Delta}{2} + \frac{L}{2}$	(12)B
			Where S is given from formula No. (14)B L is given from formula No. (3) Above 960 feet RADIUS. $T = (R+S) \tan \frac{\Delta}{2} + \frac{L}{2}$	(12)B
5 (*b*)	Fix point, O, in the field measuring length T from apex point, A, or point of intersection of tangents.		Where S is given from formula No. (14)B L is given from formula No. (4)	
6	X ORDINATE. Find final X ordinate at end of transition. R and L being known. Mark points B and B_1 in the field measuring "X" feet from point O and O_1. $X = O\,B = O_1\,B_1$.	FOR ALL RADII. Graph No. (1) X. Scale for X on left hand side. Also graph No. 4 (enlarged scale). Deduct reading in graph No. 4 from Length of transition to get X more accurately.	0 to 300 feet RADIUS. $X = 11{\cdot}5\sqrt{L}\left\{1 - \left(\frac{5{\cdot}75}{\sqrt{R}}\right)^2 \times \frac{1}{5\times\underline{\lvert 2}} + \left(\frac{5{\cdot}75}{\sqrt{R}}\right)^4 \times \frac{1}{9\times\underline{\lvert 4}} - \left(\frac{5{\cdot}75}{\sqrt{R}}\right)^6 \times \frac{1}{13\times\underline{\lvert 6}} + \text{.....................}\right\}$....	(8)
			Alternatively $X = L - \frac{L^5}{40\,(RL)^2}$	(8)A

Serial No. of Procedure.	Description of Procedure.	Number of graph to be used.	Alternative formulae which may be used in absence of graphs.	Formula No.
	.. ..	... ...	L being given from formula No. (3) 300 feet to 960 feet RADIUS $X = L$	(17)
			where L is given by formula No. (3) ABOVE 960 feet RADIUS $X = L$	(18)
			where L is given by formula No. (4)	
7.	Y ORDINATE. Find final Y ordinate at end of transition, R and L being known. Mark points Z and Z_1 in the field measuring Y feet from point B & B_1 at right angles to $O\ B$ and $O_1\ B_1$, respectively.	FOR ALL RADII. Graph No. (1) Y Scale for Y on the right hand side.	0 to 300 feet RADIUS $Y = 11{\cdot}5\sqrt{R}\left\{\left(\frac{5{\cdot}75}{\sqrt{R}}\right) \times \frac{1}{3} - \left(\frac{5{\cdot}75}{\sqrt{R}}\right)^3 \times \frac{1}{7 \times \lvert\underline{3}} + \left(\frac{5{\cdot}75}{\sqrt{R}}\right)^5 \times \frac{1}{11 \times \lvert\underline{5}} - \text{etc. etc.} \right\}$	(6)
			Alternatively $Y = \frac{L^2}{6R} - \frac{L^4}{336R^3}$	(6)A
			L being found from formula (3). 300 to 960 feet RADIUS. $Y = \frac{L^2}{6R}$	(10)
			L being calculated from formula No. (3). ABOVE 960 feet RADIUS. $Y = \frac{L^2}{6R}$	(10)
			L being calculated from formula No. (4).	

Serial No. of Procedure.	Description of Procedure.	Number of Graph to be used.	Alternative formulae which may be used in the absence of Graphs.	Formula No.
8.	Intermediate points or Abscissa x_1, x_2, x_3, x_4 etc. Divide the length L, of the transition curve into either 5 or 10 parts, 5 for Radii below 300 feet and 10 for radii above 300 feet. Each part equals l. *Either* calculate the corresponding intermediate distances $x_1, x_2, x_3 \ldots x_5$ from the formula, No. 9A, which is rather troublesome and mark the points x_1, x_2, etc. so found directly on line OA in the field. *Or.* Find $x_1, x_2, x_3 \ldots x_5$ automatically in the field by taking equal measurements of $l_1, l_2 \ldots l_5$, measured along the transition curve and drawing perpendiculars y_1, y_2, y_3, y_5 down to line, OA. The points $p_1, p_2 \ldots p_5$ on the required transition are thus found automatically in the field without the necessity of finding $x_1, x_2, \ldots$ etc. Upto 300 feet radius 5 divisions are sufficient. Beyond 300 feet radius 10 divisions are better.	Graph unnecessary.	0 to 300 feet RADIUS. $x_n = l_n - \frac{(l_n)^6}{40(RL)^2}$ .... where $l = \frac{L}{5}$ for 5 divisions and $\frac{L}{10}$ for 10 divisions. $L = 11{\cdot}5\sqrt{R}$ from formula (3) 300 feet to 960 ft. RADIUS. $x_n = l_n$ where $l = \frac{L}{5}$ or $\frac{L}{10}$ $L = 11{\cdot}5\sqrt{R}$ . . . .from formula (3) ABOVE 960 feet RADIUS. $x_n = l_n$ where $l = \frac{L}{5}$ or $\frac{L}{10}$ and $L = \frac{340740}{R}$ ....(4)	(9)A

Serial No of Procedure.	Description of Procedure.	Number of Graph to be used.	Alternative formulae which may be used in the absence of Graph.	Formula No.
9.	INTERMEDIATE "Y" ORDINATES. Calculate the y ordinate at each corresponding x ordinate, and plot in the field, care being taken to draw the y ordinates at right angles to the tangent line. 5 ordinates, y_1, y_2, y_3 etc., upto 300 feet radius, 10 ordinates for curves above 300 feet radius. If the x ordinates are calculated from formula given above, the y ordinates may be drawn at right angles to each of the x points along the tangent line thus fixing the intermediate points p on the curve. If the x ordinates are not accurately calculated from formulae given above, lay out lengths $l=\frac{L}{5}$ or $\frac{L}{10}$ from point O by tape in the field and draw p_1, y_1, at right angles to tangent OA in the field. This fixes p_1. Then from point p_1 measure $l=\frac{L}{5}$ or $\frac{L}{10}$ by tape in the field drawing $p_2 x_2$ at right angles to OA and equal to y_1 by means of another tape. This fixes p_2. Repeat till point Z is reached.	FOR ALL RADII Graph No. 3.	0 to 300 feet RADIUS. For Five Divisions. $y_1=\frac{(\cdot 2)^3L^3}{6RL}-\frac{(\cdot 2)^7L^7}{336(RL)^3}$ $y_2=\frac{(\cdot 4)^3L^3}{6RL}-\frac{(\cdot 4)^7L^7}{336(RL)^3}$ ... ... $y_n=\frac{(\cdot 2n)^3L^3}{6RL}-\frac{(\cdot 2n)^7L^7}{336(RL)^3}$ L being found from formula No. (3)	6A.
			ABOVE 300 feet RADIUS. Ten Divisions. $y_1=\frac{(\cdot 1)^3L^3}{6RL}=\cdot 001Y$ $y_2=\frac{(\cdot 2)^3L^3}{6RL}=\cdot 008Y$ $y_3=\frac{(\cdot 3)^3L^3}{6RL}=\cdot 027Y$ $y_4=\frac{(\cdot 4)^3L^3}{6RL}=\cdot 064Y$ $y_5=\frac{(\cdot 5)^3L^3}{6RL}=\cdot 125Y=\frac{1}{2}S$ $y_6=\frac{(.6)^3L^3}{6RL}=\cdot 216Y$ Y being found from formula given in procedure 7 or from graph No. 1 (l) (y)	10

Serial No. of Procedure.	Description of Procedure.	Number of Graph to be used.	Alternative formulae which may be used in the absence of Graphs.	Formula No.
	.. .. ..	... ...	$y_7 = \frac{(\cdot 7)^3 L^3}{6RL} = \cdot 343\ Y$ $y_8 = \frac{(\cdot 8)^3 L^3}{6RL} = \cdot 512\ Y$ $y_9 = \frac{(\cdot 9)^3 L^3}{6RL} = \cdot 729\ Y$ $y_{10} = \frac{(1)^3 L^3}{6RL} = 1\cdot 0\ Y$ Y being found from formula given in procedure 7 or from graph No. 1(1)(Y)	
10.	CIRCULAR ARC. Having fixed the ends of the transition curve by procedure No. 7, and R by procedure 4, join ZZ_1 by a circular arc of radius R. PROCEDURE. Calculate $\lambda = B_1X_1$ from formula. Join ZZ_1. Bisect it in the field. Fix X in the field, $X_1B_1 = \lambda$, being at right angles to ZZ_1. If ZX_1 is greater than 25 feet subdivide into two more points X_2 and X_3 in a similar manner, using chord, X_1Z_1 instead of ZZ_1 and λ_2 instead of λ_1. Repeat till points X_1, X_2, X_3, etc. are not more than 25 feet apart. The transitions may meet in the centre or be only 5 or 6 feet apart in which case the above procedure is unnecessary.		FOR LARGE VALUES OF ANGLE ZMZ_1, (ABOVE 45°), Verify angle $ZMZ_1 = d° = \frac{L}{R} \times \frac{180}{\pi}$ in degrees. Using formula 3 or 4 for L according as radius is less than or greater than 960 feet. If ZMZ_1 is greater than 45° calculate λ_1 from Formula $2R\lambda_1 = \lambda^2 + \left(\frac{Z_1Z}{4}\right)^2$ ... . This will seldom occur. FOR SMALL VALUES OF ANGLE ZMZ_1, (BELOW 45°), $X_1B_1 = \lambda_1 = \frac{(Z_1Z)^2}{8R}$ $X_2B_2 = \lambda_2 = \frac{(X\ Z)^2}{8R}$	(19) (17) (18)

Serial No. of Procedure.	Description of Procedure.	Number of Graph to be used.	Alternative formulae which may be used in the absence of Graphs.	Formula No.
11.	APEX DISTANCE, AX_1 Find out Apex distance, $A = AX_1$ Check up and see if distance from point, X_1 actually found by procedure 10, to $A = AX_1$ actually agrees with result of formula 13. If not, go over the whole work again and find out where the mistake lies.		$AX_1 = (R+S) \ \text{Sec} \ \frac{\Delta}{2} - R$ .... S being calculated from formula No. (14)	(13)
12.	LENGTH OF CURVE $Z X_1 Z_1$. Calculate length of curve $Z X_1 Z_1$ from formula (16). Verify in the field if this length measured around the circular arc agrees with calculated results. If not, revise whole procedure and correct the mistake.		BELOW 960 Feet RADIUS $Z X_1 Z_1 = \frac{\pi R d^2}{180} - L$ .... d being in degrees and L being calculated from formula No. (3.) ABOVE 960 Feet RADIUS. $Z X_1 Z_1 = \frac{\pi R d}{180} - L$ .... L being calculated from formula No. 4.	(16) (16)
13.	SHIFT = XX_1 Considerations of "shift" are not usually necessary in laying out new curves if above procedure is adopted, but are useful for reconnaissance work, and checking up work done, when transitioning old curves on an existing road. If the new radius adopted in design for improving a curve is the same as the old radius, check up after lay out if the shift as	FOR ALL RADII Graph No. 1 (S) Vertical scale for shift given on the right hand side.	BELOW 300 Feet RADIUS. $S = Y - R\,(1 - \cos \phi)$ .... or $S = \frac{L^2}{24\,R} - \frac{L^4}{2688\,R^3}$ .... L being found from formula No. (3) Y being found from formula No. (6) or (6) A. 300 To 960 Feet RADIUS. $S = \frac{L}{24\,R} = \frac{Y}{4}$	(14) (14) (C) (14 B

Serial No. of Procedure.	Description of Procedure.	Number of Graph to be used.	Alternative formulae which may be used in the absence of Graphs.	Formula No.
	actually measured at site agrees with the calculated amount.		L being found from formula No. (3) ABOVE 960 Feet RADIUS. $S = \frac{L^2}{24\,R} = \frac{Y}{4}$ .. .. L being found from formula No. (4).	(14) B
14.	Work out total amount of super-elevation to be given at point $Z\,Z_1$ where the transitions join the circular curve (see table in column 4). Also the increase in road-width *vide* column 4. The full super-elevation E, and full increase in road-width are attained at points Z and Z_1 at the end of the transition and remain constant throughout the circular arc $Z\,X_1\,Z_1$. The method of gradually introducing super-elevation and increased width from zero to full value are shown in the Longitudinal Section figure 13. *N. B.*—Formula No. (20) assumes a 9 feet traffic lane. If, however, the Indian Roads Congress standard of a 10 feet traffic lane is adopted, the formula becomes:— Increased width $= W + w = W + \frac{W}{10} \times$ col (c)	See Table on right. No Graph.	See table below. Increased width $= W + w = W + \frac{W}{10} \times$ col. (c.) ..	(20)

col. A. Radius, R In Feet.	column B. Super-elevation to be adopted (fraction of Road width $= e$): Standard Practice.	column B. Orissa Circle Practice.	column C. Increase in road width in feet for each traffic lane. Average standard practice: Theoretical	Average standard practice: Actual.	Orissa Circle Practice Feet.
30	·10	·166	6·7	7	4·5
50	·10	·125	4·2	4·5	4·5
100	·10	·125	2·0	4·5	4·5
150	·10	·104	1·33	4·0	4·3
200	·10	·104	1·0	4·0	4·1
300	·10	·094	0·67	3·0	3·7
400	·10	·094	0·5	3·0	3·3
500	·10	·084	0·4	3·0	2·9
600	·10	·084	0·3	3·0	2·5
700	·10	·062	0·28	3·0	1·7
800	·10	·062	0·25	2·0	1·7
900	·10	·042	0·22	2·0	1·3
1000	·10	·042	0·2	2·0	0·9

Serial No. of Procedure.	Description of Procedure.	Number of Graph to be used.	Alternative formulae which may be used in the absence of Graphs.	Formula No.
			E = actual super-elevation at the commencement of circular curve $ZX_1 Z_1$ $= e\ (W+w)$.	
15 A	Draw longitudinal section giving Reduced Levels as per figure 13 to scale for each side, filling-in the correct values for width and super-elevation. This is especially important in the case of curves which are on a slope or grade. The actual grade will be the Datum line shown horizontally in figure 12. This Datum should be drawn at the required grade or slope angle in the Longitudinal section (with R. Ls.), and all other levels on the inside and outside of curve should be calculated from it.		See formulae in diagramatic longitudinal section Fig. 13 which is self-explanatory.	
15 B	Fix the required levels and widths at points A_1, O_1, B and Z in the field. Widths to be laid out half on either side of centre line. Intermediate level points may be fixed by boning rods.			

PAPER No. D—40.

TRACKWAYS FOR RURAL ROAD DEVELOPMENT

By

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The writer first began nearly 20 years ago to think of trackways, as a solution in certain cases of the stage development of rural earth roads. Since then he claims to have been the principal, if not the sole protagonist —or, as some possibly think, faddist—in respect of these. In recent years there has been propaganda and demonstration of trackways, and there is little that is now left to be said and little fresh material to work into a Paper for the Congress, which is a body entitled to expect original communications.

2. But this Paper has been written in an attempt to review the position as it is and as a parting shot at members of the Congress whose opinion should influence rural road policy. We are all agreed that one of the most urgent needs in India today is to improve rural transport facilities. Economic and social progress and that education which follows a widened outlook will all follow—and more rapidly than by any other means,—the breaking down of the isolation and relative stagnation of the villages which result from bad roads. The motor bus cleaves to the metalled road and still fails to play its potential part in providing convenient, comfortable and rapid transport to and from the immense number of villages which lie off the main metalled roads. It is because of this isolation and stagnation that the more highly educated gravitate from the village to the town, and it is because of this that the benefits of prophylactic and curative medicine do not reach the mass of the rural population as they should. An all round improvement of rural roads is overdue, but with the bullock cart, as it is, this improvement appears to be financially impossible if we cannot get away from the orthodox methods and materials of metalled road construction and maintenance. The writer is whole-heartedly in favour of persuading the community to see the bullock cart problem in its true perspective, and of spending generously to subsidise conversion to pneumatic tyres, but that revolution in rural transport will take years to effect and the country cannot afford to stagnate in the meantime. It is suggested, moreover—

(1) that the bullock will remain as the motive power of rural transport for many years, so long at least as the bullock pulls the plough, partly because agricultural holdings are fragmentary ;

(2) that, if earth roads remain no better than they have been for centuries, or indeed deteriorate under increasing traffic, it will be the more difficult to persuade the cartman

to change a cart which has been evolved for such conditions ; and that, therefore, every extension of better roads will remove an obstacle to the improvement of the cart both as a transport machine and as a road user, by conversion to pneumatic tyres, or otherwise, if there is an otherwise ; and

(3) that trackways, if properly planned, are a stage in development that can be worked into the better road that may in time follow.

3. It is unnecessary to remind the Congress that, excluding the immense milage of village roads, more than half of our extra-municipal roads are natural earth. Nor is it necessary to point to the thousands of miles of excellent earth or lightly surfaced roads in the United States and—as Mr. Murrell stated in his Paper last year—Australia. The scientific stabilization of soils has played a considerable part in the development in America. At the instance of this Congress, research in this direction has been initiated in India in recent years. It should be fruitful in many ways, but it is apparently beyond the wit of man to produce an earth road that will carry heavy cart traffic as carts now are. It has been roughly estimated* that there are possibly 50,000 miles of earth road already carrying traffic that is beyond their capacity—traffic which would increase were the roads to be improved. In this connection a brief account of what happened on the roads in the Punjab about 15 years ago, is apposite.

4. Attempts were being made by demonstration, to persuade District Boards that earth roads could be saved and improved by proper sectioning and some blending of soils. A length of about ten miles in each district was selected for this demonstration. This was so far successful that it was followed for a time by fairly extensive improvement and maintenance by machinery ; but it is, it is believed, a fair statement to say that progress was eventually halted by the fact that the traffic was or soon became beyond the capacity of any earth surface. A subsequent development was the reservation of a small strip along one side of the road for light motor traffic and pathetic contentment that the rest should remain bad. This development has at least shown that there is an immense milage of earth roads that, relieved of the loaded bullock cart, can well serve other traffic. But the experience with one of the earlier demonstration roads may be cited as typical. It had been so bad that practically all transport was by pack. But the soil was good and, by a little widening, grading and blending of soils, a first class earth road was provided. *Tongas* and a couple of light buses began to run at once to the great comfort of the people, and every one was delighted. But traffic rapidly increased and before long pack transport was replaced by bullock carts and the road began to deteriorate, and to revert to its previous condition. That was some years ago; the carts may remain but the buses and many of the *tongas* have probably given up. Goods transport may have reverted to pack, and, the inhabitants are probably convinced that nothing short of a metalled road is any good to them. Translate that

* Proceedings of the Sixth Annual Meeting of the Indian Roads Congress, Bombay—President's Address.

example into 50,000 miles of road in the same case and you have a measure of the problem.

5. Having regard to the possible and indeed desirable rise in the wages of rural labour and the price of materials, it is not wise at the present day to build a metalled road unless maintenance provision can be guaranteed at a rate that can seldom be less than Rs. 500/- per mile per year. Indeed if the road is to be surface treated, Rs. 800/- is a low figure. But, at Rs. 500/-, 50,000 miles of metalled road will cost two and a half crores a year in perpetuity to maintain and, after the almost inevitable periods of temporary neglect, large sums to restore. The present provision for extra municipal road maintenance, "Provincial" and "Local", in British India is about four and a quarter crores. It is generally believed to be inadequate, and it is difficult to get at that. With trade and revenue cycles aggravated by the vagaries of the monsoon, the main problem in India is not so much to provide the original cost from occasional surplus budgets, or even from loans, as to undertake the additional perpetually recurring and unforgiving liability for maintenance. The need for the improvement of rural communications is urgent and real. Can we contemplate as a practical and immediate policy one that will require the addition of two and a half crores or 60 per cent, to the present maintenance bill, which is already inadequately financed? Should we not say that the existing very large investment in roads should first be adequately reconstructed where necessary and properly maintained before we add so largely to the liabilities? If that is so, are we then to sit back and do nothing until very much larger and more regular provision is made for maintenance? Even if the money were available, is the orthodox metalled road, with or without surface treatment, the best investment, or can we not find something serviceable that is less costly to maintain and less dependent upon that essential to ordinary metalled roads, regular and unfailing yearly provision for maintenance?

The writer believes that one answer is to be found in trackways which can carry the loaded cart and leave us with earth roads which, particularly with the help of science, we should be able to maintain for other traffic at a standard comparable with that of the United States and elsewhere and at a recurring cost of Rs. 100/- to Rs. 150/- per mile per year. In cement concrete, the trackways may be expected to last for 15 to 20 years. That should suffice for the present, but if, before the expiry of that time, it becomes possible to advance the road a stage further, trackways still have their use or "salvage value."

6. It is necessary to emphasise and even to labour the financial case for trackways because there are still people who do not see the justification for spending eight or ten thousand rupees a mile in first cost to provide no more than a good earth road for traffic other than carts, when an orthodox metalled road can be provided for the same or even less money. Assuming that trackways can be built for Rs. 8,000/- per mile and maintained for Rs. 150/- per mile per year, and taking equated payments spread over 20 years at 7 per cent to include interest at $3\frac{1}{2}$ per cent and redemption of capital, the total cost of trackways may be

compared with metalled roads at various costs for construction and maintenance as follows :—

TABLE I.

Comparison of total cost of trackways with metalled roads over 20 years.

	Trackways.	Metalled Road.		
CAPITAL COST.	8,000	5,143	7,500	15,000
ANNUAL COST.				
1. Equated payments ..	560	360	525	1,050
2. Maintenance. ..	150	350	500	800
Total ...	710	710	1,025	1,850
Total in 20 years ...	14,200	14,200	20,500	37,000

It will be seen that, if trackways can be provided for Rs. 8,000/- a mile and maintained for Rs. 150/-, it is necessary, in order to compete in cost, to have a metalled road that can be built for about Rs. 5,000/- and be maintained for Rs. 350/- per mile per year. Such a metalled road will not, of course, be surface treated with tar or bitumen. It will be dusty and little better, sometimes worse, than a good earth road. Trackways in an earth road are not intended for motor transport and it is indeed said to be difficult to drive a motor vehicle on them at any speed for any length of time. But after heavy rain, for instance, when there is little or no bullock cart traffic moving, and the earth road is soft, it is quite possible with care to drive a motor vehicle along them, when it would not be possible to move without.

7. Trackways are not original. They are possibly a revival of something of great antiquity in Europe. The derivation of the word "tram" is from a Northern European word meaning a balk or beam of timber and a "tram road" was a road with wooden, stone, or later, iron wheel tracks. Trackways for India, however, were first suggested, to the writer at least, by the simple fact that it appeared to be less costly to lay the ruts in durable materials than to make and maintain a macadam road to be cut into ruts, while the rest is of very little use.

8. The first trial was made near Lahore in 1923-24. An earth road was carefully levelled and drained with a wide formation and at the lowest level compatible with adequate drainage, and a short length of trackways was laid along this. Unfortunately, the road was shortly afterwards selected for development as a trunk road and the trackways were buried under an orthodox but unnecessary embankment with a metalled road on the top.

9. To digress for a moment, it is the writer's firm conviction that for years, road designer in India has been wrongly dominated by railway practice, and that for every mile of road that is too low and liable to

inundation, hundreds of miles are spoiled by excessive embankment. The edges of a bank are always damaged by erosion. The "cut it out and hang it up to dry" section cannot retain the moisture-content necessary for stability. The bank is a frequent source of accidents, particularly to bullock carts when the bullocks take fright; and lastly, and in this case also least, unnecessary money is wasted in earth work to build and maintain the bank. There are areas of high rainfall and flooding rivers where embankment is a necessary evil. But there are many areas of low rainfall and absence of general inundation where they are an abomination. Possibly the best lightly metalled roads in India are in Jaipur State. These have a formation about 40 feet wide, good berms on mother earth and the crown 9 inches or so above the natural surface. A railway must be on a bank partly because it must never be topped and partly because of its limiting gradients. The draftsman who, in a road project, uses on the longitudinal section a straight edge sometimes over a mile long, to scale, is still dominated by his training based on railway engineering. If a road is occasionally topped, little harm is done if it has a flat or stream-lined cross section or profile. Indeed an occasional soaking will do a lot of good to many roads. With our mixed traffic, we want wide roads with plenty of room on the *kachha* for the miscellancy that uses them. Every unnecessary foot in height of bank makes it more expensive and difficult to widen as well as to maintain the road.

10. To return to trackways, for some years the writer was not in a position to carry out further experiments and abandoned the subject in view of general scepticism and of sobering experience that when the people who are to do a thing say in advance that it " won't work", it does not. In recent years, however, it has become more and more obvious that earth roads cannot be made to carry heavy cart traffic, and that, even if loans could be raised for construction, the recurring cost of a substantial additional milage of metalled roads at present presents insuperable obstacle to adequate development in that way. Arrangements were, therefore, made with the Provincial authorities to lay down two short lengths of trackways, less than a mile each, for demonstration to the First Indian Roads Congress. One of these was on the Jaranwala-Sayadwala road in the Punjab and the other on the Badli Railway Station road near Delhi.

11. (1) About the same time trackways, or "creteways" were tried on an earth road in Assam. The idea was taken from similar successful work in Southern Rhodesia and East Africa where wheel tracks in both cement concrete and bituminous materials had been found to provide a satisfactory and economical form of road for light, mostly motor, traffic. The Assam " creteways " had the same object.

(2) Some slab-stone trackways were laid in 1931-32 in a sandy stretch of the unmetalled part of the Bharatpur-Jaipur road in Bharatpur State. These again were satisfactory. They were, of course, used by all vehicles which are not numerous; and, when meeting or passing another, one vehicle had to pull off, but this did not constitute a serious nuisance.

(3) " Creteways " have also been laid in the ruts of metalled roads, satisfactorily in a *kankar* surface in the United Provinces but not so successfully, it is believed, in stone macadam in the Central Provinces on the Jubbulpore-Damoh road. It seems that, while the longitudinal joint between a concrete side width and the rest of the road—as in what Bombay has now called "Conphalt"—does not give trouble, the four joints with "creteways" laid in stone macadam give constant trouble. For this type of construction it is necessary that the material of which the road crust is formed should have, like *kankar*, very good binding properties.

(4) These instances are, however, of trackways or "creteways" designed for a somewhat different purpose to that with which this Paper is concerned.

12. (1) A further short length of trackways in an earth road of one mile has been laid in the Punjab on the Lyallpur-Jhang road as the separate road for bullock carts, as an experiment with segregation.

(2) An experimental length laid in Sind some years ago has been so promising that the Sind Public Works Department now contemplate the use of cement concrete trackways as a standard type of construction for rural feeder roads.

13. Finally in order to test and to demonstrate the traffic value of trackways in an earth road on a somewhat longer scale than heretofore, a length of about five miles has been laid on the Gohana-Sonepat road in the Punjab. This was completed in March 1940 and will be seen by those attending the Congress in January 1941. They can form their own opinions.

14. *Technique of construction of trackways.*

(1) Various forms of construction are possible and have been tried. In certain rare localities, suitable slab stone can be quarried and this should be very satisfactory, provided the slabs are of sufficient thickness, say 6 inches. For the general case, cement concrete seems, at present, to be the most economical wearing surface, but whether the trackways should be made wholly in cement concrete or in thin cement concrete slabs upon some other foundation depends to some extent upon local conditions and materials available. The mixing and laying of relatively small volumes of concrete along an often dusty earth road requires close supervision and considerable care. With two-course cement concrete work, say four inches of lean and two inches of standard concrete, these difficulties would obviously be increased. Trackways of stone water-bound macadam, whether surface treated or not, would probably ravel at the edges and would be troublesome and costly to

repair and renew. *Kankar* has much more cohesion than stone but would also be liable to ravel and would only serve for very light traffic. Brick-on-edge laid dry has also been tried but not, by the writer, for any permanent purpose. It appears to be suitable only for very light traffic, and while the bricks can doubtless be turned after a certain amount of wear, repairs would be troublesome and probably expensive. With the exception of the Bharatpur stone slabs laid in Bharatpur and on a short length on the Badli Railway Station road, the trackways with which the writer has been connected have invariably been surfaced with Portland cement in the normal proportion of 4:2:1 more or less, adjusting the actual mix to the materials, in order to get a workable mix with a suitable cement-water ratio.

(2) *Jaranwala-Sayadwala Road, Punjab.* Figures 1 to 5 (Plates I and II) give the details of the five sections of the trackways laid on this road. The first section (Figure I) was two furlongs in length and the remainder one furlong each. The first three sections were completed in November 1934 and the remaining two about a year later, when also were laid two sections of a nine feet, light section, concrete road for the purposes of comparison, each being one furlong in length and being—

(a) 2 inches of cement concrete on hand-packed brick-on-edge soling; and

(b) bonded cement concrete and brick with a thickness of concrete of 2 inches over all and 3½ inches in the "web".

Both these sections of 9 feet road (Figures 6 and 7, Plate II) were still in existence up to a few months ago, that is five years after construction, but had broken up badly and have since, it is believed, been covered with some bituminous premix carpet. The quality of the concrete in these did not appear to have been good and it is noteworthy that in section three (Figure 3) of the trackways the premix inlay rapidly wore out leaving only two inches of cement concrete which has stood well. This is, of course, on a very heavy foundation of 9 inches of well-rammed lime concrete. But it is possible that the failure of the 9 feet concrete road is due, in part at least, to an unsuitable foundation. The writer has always suspected dry brick as a foundation for very thin crusts or carpets as giving inadequate distribution of load leading to the pulverising and loosening of the sub-grade and as tending to rock and move.

(3) To digress once more, owing to the difficulty of obtaining stone in the Western Punjab, about 12 years ago after preliminary satisfactory small scale experiments, a length of 5 miles of 2-inch sand-bitumen carpet was laid on a brick-on-edge soling. This shortly became a total failure partly apparently owing to the mix having been too "dry", but

upon taking up certain sections, it was found that the sub-grade under the dry brick was very loose and pulverised and obviously afforded an inadequate and unstable foundation.

(4) To return to the trackways on the Jaranwala-Sayadwala road, it will be noticed that in two sections a heavy foundation of 9 inches of lime concrete was given. The reason for this was not because such a heavy foundation was necessary on a good sub-grade, but because the work was done in a hurry (in order to demonstrate it to the First Roads Congress) and the road being badly cut up and rutted, it was not certain that a hard bottom could be found or made at a higher level. Actually it evidently was, since the sections on 4½ inches lime concrete appear to be as good as those on 9 inches. The inset cement concrete "sleeper" under the joints is now seen to have been unnecessary, but this was one of the earliest experiments. It is noteworthy however, that, while the joints have abraded somewhat, there is, as would be expected, no sign of depression and consequent cracking two or three feet back from the joint, which is liable to happen with plain unreinforced and unsupported butt joints.

(5) *Bituminous Inlay.* When these trackways were laid, it was feared that heavy bullock cart traffic over a period of years might cause surface wear in the concrete which would be difficult to repair, and the experiment was tried of providing a one-inch inlay of bituminous premix (Figure 3) which, it was thought, could be repaired periodically leaving the concrete intact. This premix, however, as also in the similar trial on the Badli Railway Station road, quickly wore out and was never replaced. The two inches of concrete have stood quite well and in fact the sharp arrises at the edge of the slab are still in existence six years after construction. The inlay is evidently unnecessary. The writer's present theory is that the trackways should be slightly below—say one inch—the level of the earth road which is thus "dished". This has two advantages, pre-emption against the concrete tracks becoming "proud" with consequent difficulty for carts to get on when they have got off, and against consequent damage to the edges, and the retention of a thin layer of dust on the concrete saving both that and the feet of the bullocks. There is some off-setting disadvantage in the ponding and puddling of the earth against the concrete after rain, and the layout must depend on the amount of rainfall.

(6) Photographs of the Jaranwala-Sayadwala road trackways, taken about five years after completion, and of the condition of the earth road beyond the trackways was published on the cover of "Indian Roads" of December 1939 and other photographs have appeared

elsewhere. It will have been seen from these that the trackways are still in sound condition and that the earth road is in very good order and stable for any kind of traffic other than loaded bullock carts. A further photograph* or photographs will, it is hoped, be taken in November or December during the height of the cotton marketing season. It remains to be stated that the latest census of traffic gave a total* for 24 hours as follows :—

(7) *Badli Railway Station Feeder Road.* Seven furlongs of trackways were laid in the autumn of 1934 on this road which leads from the Grand Trunk Road a few miles North of Delhi to Badli Station and to a number of villages beyond. Owing to the recent construction of a metalled road giving more direct access from certain of these villages to Delhi, the traffic on this road has greatly diminished and the test of the trackways is not severe. These were fully described in Mr. Dean's Paper read before the First Roads Congress† and need not be described again except to state that, as in the case of the Jaranwala experiment, the inlay of bituminous premix in the concrete trackways was not a success.

(8) *Trackways in Sind.* The various specifications tried in Sind have already been described,‡ but as these are the least expensive cement concrete trackways so far laid, as far as the writer is aware, the particulars, for which the writer is indebted to Mr. Parikh, may be briefly recapitulated. All the trackways consist of two strips of cement concrete each 2 feet wide, laid on a track of 4 feet 6 inches centre to centre. The cost stated below is the estimated cost *per mile* exclusive of earth work.

(1) Portland cement concrete 6 inches thick, proportion 1:2:4 for the top 2 inches, and 1:3:6 for the bottom 4 inches. Jassai stone (Quartz Porphyry). Reinforcement was used for about 3 feet near the joints, both at top and bottom in one furlong and at top only in another furlong. The work was completed in November, 1936. Rs. 9,600.

(2) Portland cement concrete 4 inches thick, proportion 1:3:6 Khathar stone (Limestone). Rs. 6,600. Completed in November 1937.

* The Paper will have to be printed and issued probably before the latest photographs are taken and the latest traffic count made. Particulars of the latter will be circulated if possible in advance of the meeting on an Addendum Slip and, if not, will be reported at the meeting.

† Proceedings of the Inaugural Meeting of the Indian Roads Congress, pages 48 to 60.

‡ Note on Road Experiments in Sind by H.B. Parikh, I.S.E., M.I.E. (India), "Indian Roads", No. XIII, June 1938, page 4.

(3) Portland cement concrete 4 inches thick, proportion 1:3:6 Jassai stone. Rs. 6,800. Completed in November 1937.

(4) Portland Cement concrete 4 inches thick, proportion 1:2:4 Jassai stone. Rs. 7,400. Completed in November 1937.

(5) Portland cement concrete 4 inches thick, proportion 1:2:4 Khathar stone (Limestone). Rs. 7,300. Completed in November 1937.

(6) Portland cement concrete 6 inches thick, proportion 1:2:4 for top 2 inches, and 1:3:6 for bottom 4 inches Khathar stone (Limestone). Rs. 9,200. Completed in November 1937.

(7) Precast slabs 6 feet 2 inches by 2 feet by 6 inches thick, with 3 deep frogs or cavities. Portland cement concrete, proportion 1:2½:4 Khathar stone. Rs. 6,200.

(*Note*):—The Jassai stone has a French coefficient of 30·1 dry and 28·6 wet and the Khathar stone a coefficient of 14·8 dry and 4·6 wet. The Jassai stone is therefore far superior.

The condition of these in August 1940 was as follows :—

(1) Not in good condition. Cracked though reinforced. Those having reinforcement at top only are better.

(2) Wearing out. Pot-holes here and there.

(3) Little better than (2).

(4) Good, some cross-cracks.

(5) Good, some cross-cracks.

(6) Very good, flawless.

(7) Completely failed in 1938.

The traffic according to the latest census taken in 1939 is as follows:—

Normal — 97·5 tons per 24 hours.

Maximum—166·4 tons per 24 hours.

The relative failure of Nos. (2) and (3) can be attributed to the lean mix. The success of No. (6) using inferior stone compared with No. (1) using supposedly superior stone has not been explained by Mr. Parikh. The traffic is light and probably the inferior stone is adequate to the traffic. The excessive cracking of No. (1) particularly since the doubly reinforced slabs were worse than the singly reinforced, suggests defects in construction

possibly owing to this having been the first section laid.

(9) *Trackways laid on the Lyallpur-Jhang road in a length of one mile of the separate bullock cart track in a total length of five miles of dual carriageway for traffic segregation.* This road which has recently been metalled connects the two district headquarters of Lyallpur and Jhang and also connects a very fertile and productive perennially irrigated area with the important and busy grain and cotton market at Lyallpur. This is part of a main trunk road from Lahore to Lyallpur, Jhang and beyond. The other approach to Lyallpur on this road is provided with a metalled and tarred surface a mile or two of which has been recently widened from 12 to 20 feet. The theory of dual carriageways is that in ultimate total cost it is cheaper to segregate than to widen because the cost of maintaining the separate widths of road, each adapted to its type of traffic, may be considerably less than the cost of maintaining the equivalent width in a single carriageway under mixed traffic. The disadvantage is, of course, that the fast traffic is left with only a 12-foot metalled road with earth berms which may be treacherous after rains, instead of the 20-foot road often quite clear of bullock carts. Against this, safety and the comfort of the cartmen which are obtained by segregation, are a great asset. Five miles of the Lyallpur-Jhang road have been given a dual carriageway but this Paper is concerned only with one mile of this in which the bullock cart road has been provided in cement concrete trackways 6 inches thick. (The other miles are in 9 feet wide cement concrete 6″-4″-6″ section and ordinary stone waterbound macadam without surface treatment). These trackways have been particularly well laid and should prove very durable. The main point for mention in this Paper is that every one, and particularly the cartmen, seem to be delighted with segregation and that the cartmen seem to be just as well satisfied with the trackways as with the concrete or macadam road, set aside for them. If trackways can be used for segregation there can be little doubt that the cost of maintenance of dual roads will be less than of widened dual purpose roads. The difficulty, however, is that gradual widening by piecemeal provision of funds is the line of less resistance than the expenditure of eight to ten thousand rupees per mile at one time to provide segregation.

(10) *Gohana-Sonepat road.* All the experiments described above consist of a length of one mile or less, and while these lengths have given very encouraging results, they are hardly sufficient to demonstrate to the road user the benefits of the system. It was decided, therefore, to make one more experiment on a sufficiently large scale, connecting one or two villages with some centre so as to

show that the whole road could, in practice, be maintained in a condition adequate to ordinary rural needs. Before urging the extension of the system to other Provinces, it was decided to make this last trial dual demonstration within reach of Delhi as being a centre from which a number of people could see it, and five miles of Gohana-Sonepat road in the Rohtak District of the Punjab were selected. Gohana is a small town about 20 miles North of Rohtak and is served both by a metalled road and railway. The Gohana-Sonepat road is an unmetalled District Board road. The soil is good.

(11) The writer wishes to emphasise that, in these various experiments he has been concerned primarily to prove that trackways are readily used by bullock carts thereby relieving the earth road of the worst traffic and enabling it to be maintained in good order for other road users. He must confess to having been concerned to avoid complicating criticism of the system by risking structural failures, and has not as a rule attempted to introduce economies in construction. He believes that once the suitability of trackways to rural conditions has been demonstrated, there will not be lacking every endeavour to reduce the cost of these. Previous experiments had shown that, given reasonably good soil, plain 6-inch cement concrete trackways with ordinary butt joints, provided with a little arbitrarily determined negative reinforcement near the joints, is sound and safe. The main specification for the Gohana-Sonepat road was, therefore, as follows:

(12) Two tracks each 2 feet wide, plain 6-inch cement concrete 1:2:4 with end negative reinforcement, two inches from the top, of four $\frac{3}{8}$-inch mild steel rounds, spaced 4 inches centre to centre in plan and running 3 feet back from each joint in the first seven furlongs. In the remaining length, owing to rise in the price of steel these were reduced to two $\frac{1}{4}$-inch rounds 3 feet long spaced 6 inches from the sides and stopping one inch short of the joint. The length of the slabs is 25 feet, plain butt joints, without sleepers or dowels, staggers. The slabs were laid in alternate bays without any space in three out of every four joints between slabs save that provided by shrinkage, but every fourth joint, *i. e.* at every 100 feet, was laid with a precast bituminous joint filler $\frac{3}{8}$-inch thick. All joints and side arrises were chamfered $\frac{1}{4}$ inch. The tracks were not laid on the centre line of the road but to the left-hand side in the direction of traffic towards Gohana, thus leaving the maximum possible width of earth road for other traffic. The earth work was kept about 1 inch proud of the level of the trackways.

(13) The available width of the road is not constant and the edge not being always straight, the distance of the trackways from the left-hand edge varies. A typical cross section, however, is given (Plate III). The above represents

the main specification. The work was completed about February 1940 and will, it is hoped, be seen by members of the Congress for themselves.

(14) The following departure from the standard specification was tried in relatively short lengths in a search for something cheaper than a six inch solid slab.

(15) *Precast vibrated slabs.* Certain experiments carried out by Mr. Kynnersley in Bombay and at Amraoti suggested that the denser and better concrete obtainable by vibrating would make it possible to use precast vibrated slabs having deep frogs on the underside, thus saving considerable quantities of concrete. The design of these (Plate IV) includes an inter-locking joint. The amount of concrete in a slab 6 feet 2 inches long, is 3·1 cubic feet, which, allowing for the extra density secured by vibration, probably corresponds to about 10 percent more concrete than the density obtained in the ordinary slabs. The latter, of course, contain 6 1/6 cubic feet for every 6 feet 2 inches length of one track and saving in materials would, therefore, be considerable. Unfortunately, the precast slabs have proved a failure and, for ordinary practice, the causes of the failure appear to be unavoidable. The manufacture of these slabs requires a vibrating table and the only one obtainable was operated by an electric motor. The slabs, therefore, had to be made at Rohtak 20 miles away from the work, where energy was available. Enough slabs were made for 1,000 running feet of complete track, but owing to the evident difficulties only 697 feet were laid, the remaining slabs being partly used up in replacing breakages and in "throw outs" from the trackways where subsidiary roads join the main road. Six feet 2-inches was assumed to be the greatest length which could conveniently be handled. Each of these slabs of this length weighs approximately 500 pounds, and they proved to be difficult to handle, and a number of breakages occurred before they reached the site.

(16) A greater difficulty, however, was the proper filling of the frogs to prevent cavitation. In order that the finished trackways shall be truly level, the sub-grade upon which the slabs are to be laid has to be carefully finished and consolidated at optimum moisture content to proper line and level. It was felt to be impossible, without great risk of unequal settlement to lay these on loose earth or cushion of a sand so that the concrete edges should bite into the cushion and ensure the tight packing of the frogs and full support of the thin concrete in the panels. Attempts were made, therefore, to make a sand-clay mix as dense as possible and to pack this into the frogs slightly "proud" of the concrete sides to provide against subsequent cavitation on drying. The slabs were then carefully turned over into the trenches without dislodging the earth

"plugs" and had to be slid along a few inches to engage the interlocking joints. Whether the construction of the vibrated slab was defective, or whether, despite the extreme care taken in laying, cavitation occurred, is uncertain. But failures began immediately traffic came on to the track-ways and eventuallythese slabs were all taken up, the frogs filled with lean cement concrete, and relaid in place. In all this kind of work, joints are a source of weakness and the necessity of keeping the length of the slabs down to 6 feet, thereby multiplying the number of joints, would possibly be a source of subsequent trouble even if the other difficulties of laying frogged slabs could be overcome. It will be noticed also that, with the interlocking joint, if a slab fails, it has to be cut out, but there is no means of inserting in its place a slab of the same length. It was estimated that, if this method had been successful, the cost of the actual concrete in the trackways would have been about Rs. 5,600/- per mile. The actual cost after providing for labour and the filling of the frogs with lean cement concrete worked out to about Rs. 8,650/- per mile.

(17) *The concrete slabs on kankar foundation.* Reasonably good *kankar* is available in the locality and it was decided to experiment with slabs on a 6-inch layer of well-rammed *kankar*. Nearly four furlongs (2475 feet) were laid with 4 inches of concrete, 1975 feet with 3 inches of concrete; and 575 feet with 2 inches of concrete. On inspection early in July it was noticed that the 2-inch slabs appeared to have ridden up slightly in the vicinity of the joints and to have separated from the *kankar* below. A more detailed examination was subsequently made with the following results: Practically all the 2-inch and many of the 3-inch slabs over *kankar* had risen at the ends to some extent owing to the scope for expansion provided by the joints being insufficient. (The spacing and arrangement of the joints was the same as in the plain 6-inch slabs). These slabs had separated from the *kankar* sub-grade or carried part of it with them for a distance of 2 to 3 feet back from each joint, and corner and transverse cracks had appeared within 18 inches of the joints (*vide* Plate V). The theory was advanced that this failure was due to the curling of the slabs at the end under temperature effects and the subsequent failure of the curled up ends under traffic, but the more probable explanation appears to be that thin slabs being more liable to be heated right through are more susceptible to temperature. Further, the lack of adhesion between the smooth *kankar* (possibly covered in construction with the film of dirt) and the slab allowed movement which exceeded the scope of the joints and caused them to push up forming a crack at some distance back from the joints. In the Concrete Pavement Manual issued by the Portland Cement Association of Chicago, the following formula appears :-

"If no intermediate cracks are to form, the distance between transverse joints is given by

$$L=\frac{2b\,t\,S+a\frac{E_s}{E_c}S}{\frac{f\,W\,b}{2}}$$

where L = distance between joints in feet.

S = allowable tensile stress in concrete in pounds per square inch.

a = area of reinforcing steel in square inches.

b = width between longitudinal joints in feet.

f = coefficient of sub-grade friction.

W = weight of concrete in pounds per cubic foot.

t = thickness of pavement in inches.

E_c = modulus of elasticity of concrete.

E_s = modulus of elasticity of steel.

Assume $\frac{E_s}{E_c}=10$, $f=2$, $S=30$ (120 ultimate, with factor of safety of 4; a low value is necessary because stresses begin while concrete is weak), $W=140$ pounds per cubic foot, a = Zero, $b=2$ feet (width of trackways).

(18) This formula gives the following approximate spacing of joints for 2 feet wide slabs :

2" thick.	–	5 feet.
3" thick.	–	8 feet.
4" thick.	–	10½ feet.
6" thick.	–	15½ feet.

These spacings can be doubled if factor of safety is reduced to 2. The formula relates, of course, to the prevention of shrinkage cracks and not to the size of panels to prevent joint failure on expansion. By the time the Congress meets, there should be evidence proving or otherwise this formula in relation to contraction cracks. Obviously, however, the expansion movement of a slab is inversely proportional to the weight of the slab multiplied by the coefficient of friction, and the experience in this case merely emphasises the fact already stressed by Mr. Walker in his Paper last year that the thinner the slab the stronger must be the bond to the underlying material. Otherwise, the length of the slabs must be considerably reduced. A close inspection of the joints also suggested that they had not been well and truly laid. The expansion joints appeared to be correct, but at certain of the butt joints, the faces did not appear to be square transversely. It is always possible that, in alternate bay construction, the first butt end may be damaged and that there will be

*"Evolution of the Thin Concrete Road in the United Provinces" by W. F. Walker, M.C., I.S.E., Superintending Engineer, United Provinces, Proceedings of the Sixth Annual Meeting of the Indian Roads Congress, pages 1 (a) to 31 (a).

unequal consolidation of the new concrete against it. An obvious mistake was made in this respect with the 2-inch and 3-inch slabs in not indenting the surface of the *kankar* or taking other special steps to develop a strong bond. The damaged joints have now nearly all been cut back to the crack and short lengths of slabs have been laid in the gaps with precast expansion joints at either end. A few of the original joints are, however, being left untouched, at least until the visit of the Roads Congress. No defects of this nature appeared during the first hot weather in the 4-inch slabs laid over *kankar*, but certain American experiments suggest that concrete "grows" with age and that compression failures may occur in the future with the 4-inch slab. In this connection, it may be mentioned that there was a few years ago one "blow up" on the Badli Railway Station road which was at the time attributed to the packing of the joint with a hard consolidated mass of fine dust, gradually worked in, by the wheels of carts. When the "blow up" occurred the joint was cleaned out and the slab dropped back into position since when there has been, as far as the writer is aware, no repetition of this. Nor has it occurred on the Jaranwala-Sayadwala road. The bond with the lime concrete appears to have sufficed.

(19) The cost of the work on the Gohana-Sonepat road reduced to rupees per mile, was:—

Earthwork	Rs.	628	0	0
Precast slabs (double track) ..	Rs.	8659	0	0
6-Inch slab	Rs.	10401	0	0
4-Inch slabs on *kankar* ..	Rs.	8260	0	0
3-Inch slabs on *kankar* ..	Rs.	6560	0	0
2-Inch slabs on *kankar* ..	Rs.	4896	0	0

Details are given in Appendix I.

15. (1) It has already been explained that the writer does not claim that trackways are the ultimate development, but it is claimed that they appear to be the best solution as a first stage development of a large proportion of the unmetalled roads which are at present loaded beyond the capacity of earth. Except in the case of a narrow village road, trackways should be regarded as a stage in development and be laid out accordingly. Certain suggestions of possible developments are illustrated on Plates VI to IX appended to this Paper. Figure 1 (Plate VI) shows the development of a village road which is not likely to be developed to a higher stage for many years. Despite the undoubted land-hunger and the obvious objections to acquiring land in areas of small holdings, the writer is convinced that it is most unwise to attempt to develop roads with inadequate width of land at the outset, and it will be seen that, in level country, a minimum width of 50 feet is proposed for village roads. This gives a formation width of 25 feet with the necessary flat side slopes and only 18 feet for borrow pits for future maintenance. In cases of absolute necessity, a lesser width is possible, but the writer is not prepared to advocate it.

(2) In many parts of India, the district road has a land width of about 65 feet and Figure 2 (Plate VI) suggests the

lay-out of trackways on such a width. Figure 3 (Plate VI) suggests the ultimate development of a road where a land width of 100 feet is available, starting with the segregation of bullock carts on trackways. A study of this section makes it clear that the siting of trackways, if they are to be used as a first stage development where adequate land width is available, needs careful consideration. Figures 4 and 5 (Plate VII) 6, 7*(a)* and 7*(b)* (Plate VIII) and 8*(a)* and 8*(b)* (Plate IX) show how, with a land width of 150 feet, a first class highway with complete segregation of traffic, and ultimate provision even for cycle tracks, can be developed, starting from the initial provision of trackways. These may be regarded as dreams for the future, but unless there is some plan of stage development from the outset, mistakes will be committed which will prove costly and obstructive in future.

16. *Summary and conclusion.* The greatest need, in the matter of roads, of the population at large is the improvement of rural communications. The greatest obstacle to this improvement is lack of money, and the greatest need is to devise a scheme of development which will improve the road-rupee ratio. Provision for the maintenance of existing metalled roads is even now inadequate in many parts of India, and the cost of maintenance is likely to rise rather than to fall with the increase of traffic and other factors. A scheme of road development, which will add substantially to the existing recurring bill before adequate provision is made for existing metalled roads, appears to be out of the question. If trackways can be provided for Rs. 8,000 a mile or less, they will be no more expensive than a metalled road costing Rs. 5,000 per mile and Rs. 350/- per mile to maintain, and in many parts of India, a very poor metalled road could be provided for that money. Where orthodox metalled roads are more expensive, trackways show an increasing economy, and it is moreover to be hoped that members of the Congress, if they accept trackways in principle, will apply themselves successfully to the reduction of their cost. Trackways, if properly laid out, provide almost immediately for partial segregation of traffic and they can form the basis of the future development of all except the narrow village road. Even if the Congress Utopia of the conversion of all bullock carts to pneumatic tyres were to come into being, segregation would still be necessary and on heavily trafficked roads something better than earth would be an advantage to the bullock cart. In that Utopia, trackways would be practically everlasting.

17. The writer must confess that the length of this Paper is somewhat disproportionate to what is, after all, a very simple device. He has, however, been impelled to set forth fully the history of trackways to date and the case for their acceptance by members of the Congress as a rational and very promising line of development for a large majority of our unmetalled roads. He trusts that the length of the Paper may be taken as the measure, in the writer's opinion, of the strength of that case.

Traffic Census at Mile 3 on Arterial Road No. 32 (Jaranwala-Sayadwala-Okara).

From 8 a.m. dated the 18th December 1940 to 8 a.m. dated the 21st December 1940.

Nature of Road Surface: Concrete Trackways

Width of surface: Two tracks, two feet each.
Width of Formation: 32 Feet.

Total weight of all Traffic in 24 hours: 257 tons.

Date and time.	NUMBER OF MOTOR VEHICLES.				NUMBER OF BULLOCK CARTS.				Total number of other vehicles.	REMARKS.
						TWO-WHEELED CARTS.				
	Lorries & Buses over 25 seats.	Lorries & Buses 25 seats.	Cars.	Total.	Four-wheeled bullock carts.	With iron tyres.	Without iron tyres.	Total.		
1	2	3	4	5	6	7	8	9	10	11
From 8 a.m. 18-12-40 To 8 a.m. 19-12-40	..	5	4	9	..	39	104	143	49	
From 8 a.m. 19-12-40 To 8 a.m. 20-12-40	..	4	2	6	..	20	112	132	75	
From 8 a.m. 20-12-40 To 8 a.m. 21-12-40	..	4	1	5	..	40	162	202	96	
Total No.	..	13	7	20	..	99	378	477	220	
Average per day.	..	4.3	2.3	6.6	..	33	126	159	73	
Weight of each vehicle. (Tons)	..	3.5	1.5	..	..	1.5	1.5	..	..	
Total weight in 24 hours. (Tons)	..	15	3.5	18·5	..	49.5	189	238.5	257	

Total average weight in 24 hours excluding cars which travelled on service road is 257 tons and 73 tongas.

Traffic census at Mile 89 F. 5 on Arterial Road No. 3 (metalled), in Lyallpur District.

From 7 a.m. dated the 18-12-40 to 7 a.m. dated the 21-12-40.

Nature of Road Surface: Tarred. Width of surface: 12 feet. Width of formation: 32 feet.

Total weight of all traffic in 24 hours: 567 tons.

Date and time.	NUMBER OF MOTOR VEHICLES.				NUMBER OF NON-MOTOR VEHICLES.				Total number of other vehicles.	REMARKS.
	Lorries & Buses over 25 seats.	Buses under 25 seats.	Cars.	Total.	Four-wheeled carts.	Two-wheeled carts. With iron tyres.	Two-wheeled carts. Without iron tyres.	Two-wheeled carts. Total.		
1	2	3	4	5	6	7	8	9	10	11
From 18-12-40 7 a.m. to 19-12-40 7 a.m.	6	42	24	72	..	39	186	225	116	
From 19-12-40 7 a.m. to 20-12-40 7 a.m.	5	39	21	65	..	40	209	249	154	
From 20-12-40 7 a.m. to 21-12-40 7 a.m.	7	45	27	79	..	41	205	246	120	
Total No.	18	126	72	216	...	120	600	720	390	
Average per day.	6	42	24	72	..	40	200	240	130	
Average weight.	@ 4 tons. =24 tons	@ 3.5 tons. =147 tons.	@ 1.5 tons. =36 tons	=207 tons.		@ 1.5 tons =60 tons	@ 1.5 tons =300 tons.	=360 tons		

Total 567 tons + 130 Tongas per day.

CORRESPONDENCE.

Comments by Mr. H. B. Parikh (Sind).

With regard to the author's remarks in the last sub-para of paragraph 14(8) of the paper, I agree with him that the relatively more wearing of Nos. (2) and (3) can be attributed to the lean mix. In the case of No. (6) as the stone used is as soft as sand used in the mortar, the surface wears uniformly and remains smooth. In the case of No. (1) however, as the stone used is much harder than sand used in the mortar, the surface wears unevenly and becomes rough. The cracks in No. 1 were due partly to possible defect in construction and partly to expansion and contraction.

Comments by Mr. W. L. Murrell, O.B.E. (Bihar).

To be very frank, my estimation of the Author is such that, if I heard that he and another had a difference of opinion about roads or anything to do with roads, my first impulse would be to say with emphasis, "The other person must be wrong."

But now, in respect of this Paper, I find that I myself differ, and that fairly acutely!

I would like to discuss the Paper first from the point of view of policy towards the steel tyre on which the Paper appears to be based, and then from the point of view of the purely technical.

I was not quite sure, until I read the last paragraph in the Paper, as to the extent to which the Author recommends the adoption of cement concrete track-ways. It is seen that it is for the large majority of our unmetalled roads, that is to say motorable earthen roads and other low type surfaces such as moorum, gravel, and sand-clay roads, the total of which in British India is some 75,810 miles, *vide* "Indian Roads" for June 1938.

The Paper, para 2, states that it would be financially impossible to subsidise conversion of the bullock cart to pneumatic tyres. What about 75,800 miles of road at Rs. 9,000/- per mile?

And then, even if the existing lower-type roads could be provided with trackways, what about the remaining 73,000 miles of other roads in British India? Are these to continue to be at the mercy of the steel tyre?

Most of these higher types of road suffer severe damage from the steel tyre, and many engineers would hold that, if we could fit reasonable tyres to the bullock carts, not necessarily pneumatic tyres, we would save Rs. 200/- per mile annually on the higher types. This luxury, the steel tyre, on the higher-type roads remaining without concrete trackways would still be costing British India about 1.5 crores of rupees a year.

If we forget about trackways for the moment, and assume that the substitution of a village-made wooden or other tyre for the steel

tyre would save an average of only Rs. 100/- per mile per annum on all the roads in British India, the total saving—or prevention of waste, would be about rupees two crores annually, and a widespread village industry would be greatly stimulated.

In any case, trackways or no trackways, think of the improvements we could affect with an additional crore or two per annum !

Point 3 is that the Author appears to have abandoned hope of an improved village-made wheel. Has any really serious effort been made to improve the bullock cart wheel in the last 5000 years, except, of course, the rather unfortunately successful one of giving it a steel tyre ?

For how long is this policy of complacency and appeasement and refusal to face stern reality to be allowed to continue ? The steel tyre is the Dictator. Is it necessary to quote the example of Europe—how refusal for years past to recognise the real situation has made the final show-down and reckoning more and more expensive ?

Any person who tries to make a regular business of carrying messages, is acting illegally. He is going contra to the interests of a Central Government Department. If such practices were allowed, the public would have to pay more for their stamps.

But any private person can make the public pay more for its roads if, in order to personally gain something (savings in tyre maintenance) he decides to fit steel tyres instead of wooden ones to his cart.

The Central Government can do nothing because roads are a provincial subject. The reality of the matter is that this talk of "subjects" is bunkum. Roads are neither a Central nor a Local Government, nor a Local Self Government matter. They are a national concern and, in all matters of basic importance, the National Government should control.

Is it not the complacent tolerance of constitutional absurdities or the repeated failure to rectify important administrative defects that provide ground from which dictators spring, and from which potential Quislings draw their wherewithall ?

"If you have rats eating your grain in a mill, you do not try simply to produce more grain than the rats can eat. You try to kill the rats".

With every bit of the respect due, I suggest that Mr. Mitchell's reply to the problem is to make the mill proof against rats.

These rats can be killed in such a way that the nuisance will never recur, and I maintain that, even if India has to go to the British Parliament to give the Central Government power to make steel tyres illegal, thus killing the rats either in one fell swoop or over a limited period, India should do it.

The above is, of course, purely a personal view, and it would not have been expressed if there had not been such overwhelming evidence in the last twelve months or so that the British public are ready to scrap any sort of convention that goes against the national interest.

Before proceeding to the purely technical it is remembered that "Who's Who in Hades" gives Sisyphus as the name of the poor soul who was condemned for ever to roll a great, heavy, ball of stone to the top on incline and then to watch it roll down, before he pushed it up yet again.

MUST every one of us be a Sisyphus condemned, for the rest of our service, to keep on rolling the heavy load of road maintenance annually and uselessly up the steel tyre incline?

The readers of the Paper will have observed that the whole scheme of trackways depends on the correctness of the assumed figures Rs. 560/- and Rs. 150/-, given in Table I.

I regret very much that I cannot accept these figures.

"Equated payments Rs. 560/- per annum" is based on a presumed life of 20 years and this, from discussions in Delhi in January last, is believed to be based chiefly on the behaviour, up to date, of the cement concrete surface of the Grand Trunk Road near Benares.

I submit that the comparison is not justifiable.

In the first place, two main factors make the foundation conditions quite different in the two cases.

Loading Conditions:—

Impact effects will be greater in the case of the trackway owing to its weight being much less than that of continuous, broad, concrete pavement.

Also, owing to the lateral continuity of the broad concrete pavement, the intensity of foundation pressure due to a given wheel load will be much greater in the case of the trackways. In the case of trackways, this pressure will be very high near the ends of each component slab or length of trackway, owing to longitudinal discontinuity at the expansion joints.

Foundation Conditions:—

The continuous, broad, pavement slab keeps its foundations dry. But water can easily reach the foundations of the trackways. The dishing of the road surface described on page 56 must, in the monsoon, lead to very wet foundation conditions.

As I will now attempt to show, it is the necessarily shallow depth of the slab, only 6 to 9 inches, that makes it unable to cope with the two above-mentioned conditions.

Let us consider what would be the fairly common case of a 0.5 feet thick trackway with butt joints, on clayey soil, in the monsoon, with material weighing 100 pounds per cubic foot between the tracks.

The allowable total pressure P on the foundation is given in Rankine's formula as

$$0{\cdot}5 = \frac{P}{100}\left(\frac{1-\sin\phi}{1+\sin\phi}\right)^2$$

where ϕ is the angle of repose of the foundation soil.

Many engineers hold that ϕ for wet clay is Nil, but let us assume it to be about $15°$.

Then the factor $\left(\frac{1-\sin\phi}{1+\sin\phi}\right)^2$ becomes 0.24, and p is only 210 pounds per square foot which is to cover the weight of the slab, the live load, and impact.

Now let us assume *most favourable* conditions.

According to Rankine's formula, the foundation of the thickest slab (9 inches) in soil of high angle of repose, 40°, should be given a loading of only 1500 pounds per square foot including the weight of the trackway, the live load, and impact.

It would, therefore, seem that we should expect all but heavily reinforced concrete slabs to crack, first near their ends, and then nearer and nearer towards the centre of the length of each individual slab.

Another reason why the life of the trackway cannot be 20 years or the equated payment Rs 560/-, is that the wheels will track over a width of only 1×2 feet, instead of over a width equal to the full width of an ordinary concrete pavement, and therefore the rate of wear would be greatly increased. That the trackways described in the Paper do not show more wear is doubtless due to the comparatively light bullock cart traffic which they are being subjected to.

Furthermore, humidity and temperature variations must cause warping of the trackway, especially where the cement concrete is thin as shown on plate I.

The concrete strip will rise towards its centre owing to rain out of season, or owing to the morning sun. It will curl up at the ends with a break in the rains, or in the cool of the summer's evening. And the bullock cart wheel, in either case, will catch it bending.

There seems to be no hope at all of cheapening the cost of trackways as suggested in (ii) on page 60 of the Paper.

As regards the figure of Rs. 150 - for the maintenance of trackways given in Table I on page 52, I regret that I cannot believe that this amount would cover the cost of joint and crack repairs under reasonably heavy steel-tyred cart traffic, to say nothing of the maintenance per mile of the road for other-than cart traffic.

This completes my attempt to show that the figures Rs. 560/- and Rs. 150/- are much under-estimated and, therefore, the trackways programme even for the unmetalled part of the road system is not sound.

One result of the high original cost of cement trackways would be that, once laid down, the trackway would largely dictate as to any future re-modelling of the road.

This would not matter much if land and property acquisition were not so expensive. But they are expensive and must be avoided and, therefore, there would be great responsibility and difficulty in deciding, for any particular road, where to place the trackway.

Plates VI to IX are all right; but we must not forget the fact that trackways are proposed first for the existing 75,800 miles of unmetalled road. Not much of this will develop into arterial milage.

I claim to be as progressive as most people where roads are concerned but, all things considered, I cannot accept the concrete trackway as the solution of the problem for even the greater portion of the 75,800 miles of unmetalled roads in our minor roads triangular.

As shown in my remarks * on Paper No. H-40 "The use of soil stabilisation in the metalled and unmetalled roads in India II" I have advocated the adoption, for our minor triangulation, of a low-cost section costing about Rs. 3100 capable of easy improvement to one costing about Rs. 7200 per mile, the steel to be replaced by non-cutting non-bruising tyres.

A cause for a little surprise and disappointment is that the Delhi discussions did not bring out more about water-bound macadam for cart traffic.

On the Chas-Gulbera Road in Chota Nagpur, there used to be a water-bound macadam trackway for all traffic. It consisted of 30 × 6 inch water-bound macadam of vein quartz on well drained, stable, earth foundations with a depth of an inch or so of mooram gravel between the tracks and outside them. The steel tyred bullock cart traffic was moderate, but it was because of the increasing motor traffic, and not because of the cart traffic, that the road had to be metalled to a width of 9 feet, and surface treated.

I believe that there are two ways in which trackways can be utilised in our road system.

1. *Creteways*—In cities and in the region of big mills, brick fields, and railway stations etc., or on arterial or inter-district roads where it is necessary to protect the main road surface, or to segregate foot and slow traffic, or to do both.

But such trackways would have to be more heavily constructed and might even tend towards a slab-cum-trackway section.

2. *Waterbound trackways*—On the berm of or in conjunction with soil stabilised pavements.

I would like to express great appreciation of the Paper, and I think we should be grateful also that the Author took the opportunity (para 9) to state some very sound general principles to be followed in road design.

Author's reply to the above comments.

The Paper was intended to be somewhat provocative and to challenge discussion and criticism. It was a challenge at once to the lack of any original developments in the realm of rural road improvement and to those who regard the existing conditions with "pathetic contentment". It is true that in paragraph 2 of the Paper a reference was made to the 50,000 miles of earth road in India already loaded beyond capacity. But, in offering trackways as one of the solutions, the author did not feel that he was taking any very grave risk of there being a spate of trackway construction of that magnitude if that system were found on further trial to be radically unsound. In the time which, even in the mind of the greatest optimist, must necessarily elapse before

* *Vide* page 156b.

a substantial part of the 50,000 miles can be improved, it is a reasonable assumption that better methods, if they exist, adapted to local conditions—and there is unlikely to be any universal remedy—will surely be evolved. The author is, therefore, unrepentant for having "trailed his coat". In doing so, he expected it to be trodden on here and there. The Paper is fortunate in having attracted the search-light of Mr. Murrell's enthusiasm—but the author is somewhat surprised at having drawn, also, the fire of accusation of being in some relationship with Sisyphus (although it is Mr. Murrell who is rolling a great heavy wheel), Quisling and the foolish miller.

2. But, بعد ادائے آداب کے*, the business in hand is to meet Mr. Murrell's criticisms as best as may be. They can be considered under the following heads:—

(1) The Paper advocates a type of construction that would be unnecessary if the steel tyres were abolished: and that the author would have been better employed in an attack on that tyre.

(2) The author considers any wholesale scheme of conversion of carts to pneumatic tyres to be financially impossible, but puts forward a proposal that involves equally astronomical expenditure, while leaving untouched the damage done to hard-surfaced roads by steel tyres.

(3) That for certain technical reasons, which Mr. Murrell sets out, the figures of Rs. 560/- per mile per year for equated payments of first cost and Rs. 150/- per year for maintenance, are fallacious; and that, therefore, cement concrete trackways are a snare and delusion. Moreover, the cost of trackways cannot be reduced.

(4) That trackways will hamper future development of the road for all classes of traffic (*c. f.* the "all-on" school), and that the future developments sketched in the Paper are visionary, since few of the roads to be developed by trackways can be expected to emerge, with the passage of time, as main highways.

3. The author would open his reply to the first line of criticism by stating as his opinion that while, with wide-spread conversion to pneumatic tyres, it would probably be found to be possible to maintain earth roads in good order at least under light (250-500 tons) bullock cart traffic, it would not, in the average alluvial soil, be possible to do so satisfactorily, if the only wheel-improvement possible is the substitution of a wide-wooden felloe for the steel tyre. This opinion is based on observations over many years in areas where the steel tyre is little used. Such a substitution would probably greatly improve the road for the bullock cart, but would not prevent the cutting of the whole formation width into relatively shallow but dusty or boggy ruts, that would impede or prevent the provision of a reasonable road for other traffic. The abolition of the steel tyre would save immense sums on the maintenance of hard-surfaced roads. It would also extend the scope of lower first-cost improvement of rural roads, but it would not by itself solve the latter problem. Moreover, the Paper does not purport to be encyclopedic. It is not a pessimistic

* ("After compliments")

surrender to the steel tyre, and even if Mr. Murrell's hypothesis is correct (that cement concrete trackways would not be necessary if the steel tyre would be abolished) it would, in the author's opinion, be wrong to neglect possible cures merely because, in time, the disease may be prevented or at least rendered less severe. With the disappearance of the steel tyre, the cement concrete trackways, properly maintained, might be even more economical in relation to alternatives than is at present claimed, since surface wear would then be negligible.

4. (1) The question of cost of subsidised conversion of carts to pneumatic tyres is one regarding which there is still, unfortunately, inadequate statistical information. But the use of bullock carts on public roads may be roughly considered under three heads :—

(a) by the professional cartman regularly using the road more or less throughout the year ;

(b) by the agriculturalist who, when not employed in ploughing and harvesting, ekes out a livelihood by carting work. The extent of this type of use depends on local conditions, *e.g.* in grass land, where fodder, away from home, is cheap, it may be extensive, but in heavily cultivated areas where cultivated fodder has to be bought, this traffic is much less ; and

(c) by the agriculturalist who only comes on to the public road to market his crop or to take his family for an outing.

(2) It is not possible at present to draw any quantitative distinction between these classes or to determine to what extent any practical distinction can be drawn. The subsidy theory rests on the basis that conversion will be of economic benefit to the owner of the cart, because the improved wheels and axles will enable him to carry a heavier load with the same bullock-power. That is undoubtedly correct in the case of the whole-time professional cartman. In the case of the third category, *i.e* the agriculturalist, who only rarely uses his cart on a public road, this consideration does not hold. Moreover, with the cart idle for much of the year and exposed to weather, the tyres would probably perish and the wheels and bearings rust. If, after three years, the subsidised wheels and tyres were useless what would happen then ?

Therefore, except in the case of the cart in constant use, the subsidy would have to be heavy, and the results of offering such subsidies on a large scale cannot at present be estimated. In proposing expenditure on trackways, there is at least the certainty of tangible improvement. The author is as anxious as anyone to see a conversion of carts to pneumatic tyres where it is economically justified, but he is equally anxious not to delude himself with false hopes that, with that in prospect, he need not do anything about the roads.

5. (1) The third criticism is probably the most serious, but is not unanswerable. It is that, since a life of 20 years cannot be safely assumed, and the trackways cannot, in Mr. Murrell's opinion,

be maintained for Rs. 150/- per mile, the total cost of Rs. 750/- per annum is a mere optimistic estimate.

(2) Mr. Murrell starts by saying that the claim of a 20 year life is based on the incorrect analogy of the concrete surface of the Grand Trunk road near Benares. It is true that the analogy was drawn, but the author places greater reliance on actual experiments in which the theoretical failure of the sub-grade, pointed out by Mr. Murrell, should have had time to develop. The Jaranwala-Sayadwala road trackways have been under traffic for nearly 7 years. There are cracks, as there are in most concrete surfaces, but they do not do any more harm than cracks in a concrete road.

(3) In his remarks on "foundation conditions", Mr. Murrell appears to throw to the winds the whole theory and hopes of soil stabilisation, because, if, given properly stabilised sub-grade under the tracks, and proper attention in lay-out and maintenance to drainage, the bearing power of the stabilised sub-grade, six inches below the surface of the road, is still, *under the most favourable conditions*, only 1500 pounds per square foot, what is to become, at the surface and below, of Mr. Murrell's low-cost section at Rs. 3,100, per mile rising to Rs. 7,200 with wheel loads not likely to be less than 500 pounds per inch width of tyre? Incidentally, at a first cost of Rs. 7,200/- per mile "equated payments" as taken in the Paper would amount to Rs. 504/- per year. Adding Rs. 250/- for maintenance—not an extravagant guess—the total would be Rs. 754/- per year, or more than the author claims for trackways. Mr. Murrell's scheme may be sounder of the two, but his figures would be no less astronomical.

(4) But to revert to foundation conditions, and assuming an effective length of track of 3 feet, we have the apparently paradoxical proposition that a load that cannot be carried, if distributed over an area of six square feet by a rigid slab of concrete, can be carried by some lightly stabilised and plastic crust of probably no greater depth.

(5) But the bearing power of well stabilised soil under trackways, provided that it can be protected from saturation in the monsoon, has been proved to be remarkable. In dry weather ordinary dry brick-on-edge trackways laid near Delhi, in the cold weather of 1940-41, have stood up to traffic, *in motor vehicles only*, of 1600 tons per day for 150 days with no apparent damage or break-down of the sub grade. No speed restriction was imposed nor did the traffic by itself slow up particularly at the trackways. The traffic included a fair proportion of lorries loaded to a total weight of 8 tons of which probably 5 tons was on the back axle which was equipped with four 30×6 tyres. Whatever allowance is made for impact and for the distribution of load by the tyres, the intensity of load on individual independent bricks in the paving must obviously have been many times that on the sub-grade under a cement concrete

trackway carrying bullock carts only. The author finds it difficult to believe that, even in the monsoon, the bearing capacity of a well consolidated sub-grade, six inches below formation level, would be as feeble as the Rankine-Murrell theory suggests.

(6) Mr. Murrell gives us another reason why a 20-year life cannot be expected,—the fact that the traffic will be concentrated tracking. That is a possibility, but the author recommends that the earth road should be maintained at a level slightly above the tracks so that they are normally covered with a light cushion of earth. Admittedly this complicates the question of drainage, but that difficulty should not be unsuperable. In any event this is one of the things that the experiments set out to prove.

(7) As regards temperature curling, which occurs with every form of concrete road, the author sees no reason to suppose that the effects will be more serious with trackways under bullock cart loads than with pavements under five-ton axle loads with high speeds and resulting impact.

(8) The author is prepared to abide by the results of actual trials to answer these queries. He hopes that someone will find a way of reducing the first cost of trackways, but he cannot accept Mr. Murrell's conclusion that the reason why those so far laid have stood is because of the "light" bullock cart traffic to which they have been subjected. The traffic on the Jaranwala-Sayadwala road is "light"—260 tons — but the individual carts are probably as heavy as are to be found anywhere in India. The road serves a fertile and perennially irrigated area, and is thus, it is claimed, a fair test. Its condition beyond the end of the trackways is thoroughly bad, and the test is typical of the type of road for which trackways are advocated. Moreover, while one must hesitate to accuse Mr. Murrell of loose thinking, it appears that he has not fully considered the actual traffic density on rural roads. Statistics are notoriously defective and incomplete, but it is well to remember that, where they have been collected, in a Paper read before the Indian Roads Congress in 1935, Colonel Haig showed that out of a total length of 3191 miles of *metalled* road maintained by the United Provinces Public Works Department, the intensity of traffic on 1827 miles, or 57 per cent of the milage, was less than 500 tons per day.* This in a densely populated Province where also it is not unreasonable to assume that the Public Works Department metalled roads are on the whole those carrying the heaviest traffic. It can, in the absence of statistics, be reasonably assumed, therefore, that a very high proportion of the 50,000 miles of unmetalled road throughout India, referred to in the Paper, carry only light traffic, i. e. less than 500 tons per day. Probably much of this 50,000 miles has only "very light" traffic, i. e. 200 tons and under, but even this is too much for the ordinary dirt road. This criticism does not seem to be apposite. It is the light traffic road that we are considering.

* "Traffic Census and Road Diagrams", by Lt. Col. W. de H. Haig, D. S. O., Proceedings of the Indian Roads Congress, Volume II, page 40.

6. There remains the criticism that, once they are laid, trackways will largely dictate future remodelling of the road. That is so, but the remedy is not to embark upon stage development without some plan of what the next stage is to be. It is not quite clear what Mr. Murrell means by his reference to the cost of land and property. Trackways are not intended for built up areas. Elsewhere in relation to the cost of road improvement, land is relatively not expensive. No road planner should accept an inadequate land width as the determining factor in development merely because the first cost of the land alone may be an important consideration. It will be far more so later. In any event, the author of the Paper is a "segregationist", if only from the point of view of public safety and convenience. Trackways, incidentally, and adventitiously may be the first stage of segregation in a previously undeveloped road. They also offer a possible means of segregation on other roads. That the ideal may be difficult and long of attainment, and that wide "all-on" roads continue to be developed from the 12-foot metalled surface, when segregation would be safer, more convenient and often less costly, do not affect the principle. If Plates VI to IX are "all right", they can be worked to from what actually exists.

7. Mr. Murrell has successfully drawn the author into a long reply. The questions raised are of great interest and importance. If anyone can produce a more economical, convenient, and district-board maintenance finance proof solution for rural road development, the author will be the first to acclaim it. In the meantime, he is unrepentant and believes that trackways are sufficiently promising to warrant extended trials.

PAPER NO. E—40.

THE STEEL TYRE PROBLEM UNFOLDS

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FOREWORD

In writing this Paper an attempt has been made at condensing it on the lines suggested by Mr. Churchill for use when submitting lengthly reports, vide (1) below. Statements of fact, quotations, etc. are set out in the appendix or notes below, each under a numeral in parenthesis.

The idea is to first read the Paper and the appended notes *simultaneously* as they occur and then, perhaps, peruse the Paper without the notes in order to have the *Paper in perspective.*

It will be remembered that, in a Paper read before our last meeting, it was pointed out that road development and improvement in India are practically stagnant, and that one of the greatest causes of this stagnation is the steel tyre of the ordinary cart.

It will also be remembered that the Congress passed unanimously a resolution (2) to the Government of India that a Committee be appointed to go into the matter.

Our request was that the desired Committee should investigate or unfold the problem, and then make recommendations to the Government of India.

The Committee has not been and, I understand, is not likely to be appointed. It is, therefore, the aim of this Paper to unfold this problem in the hope that the Indian Roads Congress itself will make recommendations or take some action. Only thus, it seems, can we hope to avoid still further stagnation.

Correspondence and personal contact with those interested in the manufacture of both the ordinary steel-tyred and the pneumatic-tyred wheel show that a solution of the problem of India's low-cost road surface (3) is not beyond our grasp.

The possibilities appear to be:—

(*a*) For the commercial or professional bullock cart (4) :—

(*i*) Existing pneumatic tyre equipment, with mass produced axle and roller-bearing wheels.

(*ii*) Existing bullock carts with "compromise" tyres, vide plan attached.

(*iii*) Existing pneumatic tyres on special rims on village-made axles and bushed hubs *i.e.* "composite" wheels.

(*b*) For the agriculturist cart (5) :—

(*i*) Existing wooden tyres.

(*ii*) "Compromise" tyres.

Governments should proclaim as soon as possible that after (say) 5 years, steel would not be allowed unless the tyre width were 4 inches minimum, on an approved type of wheel, and then only for agriculturists.

PNEUMATIC TYRE EQUIPMENT :—

The main difficulties in the way of universal adoption of pneumatic tyre *equipment with mass-produced* axles and roller-bearings are set out below :—

Price :—The average owner-driver cannot afford the initial cost, which includes the cost of both manufacture and distribution.

As regards the cost of manufacture, the producers claim that they are producing pneumatic cart tyres at the very lowest possible price, simply because they believe that the widespread use of such tyres will make possible a great mileage of low-cost roads, thus increasing motor traffic generally, and so increasing the general demand of the general public for pneumatic tyres. They are understood to openly invite scrutiny of their costs and prices even by those who are the keenest opponents of the pneumatic cart tyre, in order to prove that they are sincere in this claim.

The producers also point out that, if only the demand for pneumatic tyres were greater, they could further reduce the cost by adopting large-scale production methods. This claim is understandable, and further price reduction would be possible if a large number of Governments were to follow the lead of the Government of Sind which subsidises the users of pneumatic tyres as part of their definite continuous policy towards the future realisation of the low-cost road.

Already some Governments are trying to subsidise pneumatic-tyred carts by offering them increased cartage rates when carrying Government materials, say four annas extra per mile for lead on road metal. The quantities of materials to be shifted by each contractor are so small, however, that it does not pay contractors to invest in pneumatic-tyred carts.

Governments could subsidise through Government-controlled Co-operative Societies, and Cane and other Societies might be induced to make a speciality of advancing money to individuals for the purchase of pneumatic tyres. Such Societies have already the requisite machinery for

providing finance to small owners, or for the re-possession of pneumatic equipment in cases of non-*bona fide* borrowers.

Another means of subsidising pneumatic equipment carts, which has a special feature, occurs to me.

Once a boy has learned to ride a bicycle, he finds that cycling is a better way of getting along than walking or running, and he dreams of possessing and will strive his utmost to possess, a bicycle. The same ambition to possess is re-born when the cycling youth learns to ride a motor-cycle and, later, when he can drive a car.

The theory, then, is to give as many professional carters as possible a good taste of the comparative physical luxury of driving a pneumatically-equipped cart—to say nothing of the satisfaction of having a heavier purse at the end of the day's work.

To this end it is suggested that Provincial Governments instruct each roads division to purchase three pneumatically-equipped carts, and to hire them out to any who appear to be professional cartmen. Each cart would carry a prominent tablet "Public Hire Cart" "May be hired by any professional carter for a period not exceeding one month in any year at the rate of four annas per day." The inscription to be in the vernacular.

In divisions where there are hill roads these "Public hire carts" might be made "de luxe" by the addition of standard braking equipment.

Another factor influencing the cost to the cartman is the cost of distribution. In order to save for the carter the profit of "middle-men" and the commission of touts, Governments might consider instructing certain local officers, such as Civil or Public Works subdivisional officers, to supply pneumatic equipment for cost received, without charging departmental supervision charges, the transaction being shown in the ordinary register of deposits and cash book.

Where distribution is not on a cash but on a credit basis, the local bodies or societies above referred to could distribute without making departmental charges.

It will thus be seen that provincial governments might do a great deal to minimise and control prices without themselves incurring any extra administrative expense.

Maintenance :—Fear of trouble with punctures causes hesitation in adopting pneumatic tyres.

Owing to the low speed and pressure, the repair process need be no more complicated than the ordinary cold one, with solution, as used by the ordinary cyclist. There is a cyclist in every village, and doubtless many wheel-wrights keep cycles and do their own repairs.

Air supply would be bothersome in the case of total deflation ; but it is understood that, because they are keen on the widespread development of the low-cost road, all the important petrol companies of India are agreeable to get those of their pumps which have free-air facilities, to supply free air also to pneumatic-tyred carts.

Prejudice based on politics, or on lack of technical knowledge (6):—This is apparently a very widespread and quite a formidable obstacle to the universal adoption of the pneumatic tyre even by commercial cartmen.

As regards the allegation that the traditional occupation of the village wheel-wright will be wiped out, there appear to be at least two lines of action.

First, the building of bodies for full pneumatic-tyred equipment should be left to the village carpenters, the suppliers of the pneumatic equipment contenting themselves with issuing detailed plans, instructions in Hindi and Urdu, and even patterns, for the construction of cart bodies or for converting existing bodies to pneumatic equipment.

Second, the pneumatic tyre producers should produce a special cleated rim to enable pneumatic tyre to be fastened to village-made hubs and axles.

Note :—It would be helpful if the inscription on the walls of the tyre were to show particulars in Urdu and Hindi, including the fact that the tyre was made in India by Indians.

As regards the two alternative types of tyre proposed for the commercial cart, it was Mr. Campbell Gray (7) who suggested fitting a solid rubber tyre on the ordinary village-made cart wheel in lieu of the steel tyre, and Mr. Lakshminarayana Rao, who suggested to me that I communicate with the Director of Transport of the Travancore State, who had considered this matter of solid tyres.

Correspondence with the Director of Transport, Travancore State, however, shows that, owing to the large amount of rubber required for treading a normal four-and-a-half foot diameter village cart wheel, the cost would compare unfavourably with that of the present pneumatic cart-tyre.

As certain Bihar District Boards were to hold exhibitions of improved methods of agriculture, I offered small prizes for designs for substitutes for steel or solid rubber for the tyre of a village cart wheel. There has been no response to this yet ; but a design for a "compromise" tyre was received through the Director of Industries, Bihar.

This design and improvements, also an alternative design, are suggested in the attached sketches. So far, no "compromise" tyre has actually been constructed. Perhaps the Indian Roads Congress could do something about this, and about getting it tested.

Then came the idea of having a pneumatic tyre on a special rim bolted to the wooden felloe of the ordinary cart wheel, as was suggested by Mr. Campbell Gray for a solid rubber tyre.

This was discussed with the manufacturers of pneumatic tyres who received the idea enthusiastically, but pointed out that it was impossible, with present methods, to construct a tyre of diameter comparable with that of a village cart-wheel, yet with the necessary economical sectional width of 3 or 4 inches. The construction of such a tyre would need expensive research and new plant.

And so it boils down to this :—

If we are to retain the advantage of the easy-pulling large-diameter wheel, we must adopt the "compromise" tyre. The "Cumming" wheel is a large diameter wheel with a steel tyre about 4 inches wide, but it would damage many types of low-cost road and, therefore cannot be accepted.

This brings us to the third alternative for the commercial cart, which might be called the "composite wheel."

The principle here is to encourage the use of the ordinary axle and the village-made hub by selling the ordinary pneumatic cart tyre complete with a special rim and cleats a few inches long by which the rim can be fixed to the hub by the village wheel-wright.

No sketch is made of the proposed arrangement as the manufacturers will be the best authority to make a design ; but the rim would resemble the detachable rim used on motor cars a few years ago, the cleats being of light but stiff design, and rivetted or welded to the rim.

This arrangement, of course, would not have the advantage of the large diameter of the ordinary cart wheel which minimises the effect of axle friction. On a smooth, hard road the proposed 36-inch diameter pneumatic-tyred wheel with plain bushed hubs, or "composite" wheel, would need nearly 50 per cent more tractive effort than the ordinary 54 inch diameter cart wheel, for the same axle load. The lighter weight of this composite wheel and the superiority of the pneumatic tyre over the steel tyre on non-rigid pavements such as an earthen road, would do much, however, to make the rural pay-load of the "composite" wheeled cart comparable with that of the ordinary cart.

The composite wheeled cart would, of course, be ideal where the main considerations are bulk or comfort rather than weight *e.g.* furniture carts or passenger vehicles.

It may please be understood that neither the "compromise tyre" nor the "composite wheel" are suggested as serious rivals of the pneumatic-tyred cart with roller bearings. They should properly be described as necessities arising from the necessity for the low-cost road and the impossibility of every carter being able to purchase the more efficient equipment.

The flexible tyre is Science's gift to the low-cost road engineer. The roller-bearing is, or should be, her gift to the bullock.

RESTRICTION IN THE ACTUAL USE OF PNEUMATIC TYPES.

There are several ways in which restriction stands in the way of the universal adoption of pneumatic tyres for commercial carts

Restriction of pay load :—

No professional carter is going to lay out a (to him) large sum for the purchase of pneumatic equipment unless he can recover the outlay by carrying a heavier payload.

In Calcutta, bullock cart drivers are allowed a payload upto 45 maunds; in Bombay only of 20 maunds. In places like Bombay it is, therefore, not likely that commercial carters will go in for pneumatic equipment.

Restriction of use of roads :—

Prejudice (6) has already been shown to be one cause of restriction. Another District Board (8) has withdrawn permission for pneumatic tyred carts to use the crest of the road formation, a privilege which had been a great inducement for carters to fit pneumatic tyres.

It is perfectly true that, on many narrow-crested roads, the slow-moving carts *do* obstruct motor traffic, but the pneumatic-tyred cart owners hold that their loads are vitally important for local prosperity, that the motor traffic is small, and that the District Board is not justified in spending public money for the maintenance of motor traffic alone.

Obviously, the restriction should apply, at most, only to the narrow-crested roads. Equally obviously, all narrow-crested road formations should be widened to a minimum width of 20 feet crest. Provincial governments might help by ear-marking a percentage of motor-vehicles taxation or grants-in-aid for the widening of road crests, favouring those local bodies which likewise earmark a portion of their local funds for the same purpose. An additional method of achieving the same result would be to divert a portion of the funds now allotted for some steel bridging projects, for which steel is now very expensive or even unobtainable, to simple earthwork and turfing where road formations urgently need widening.

In this connection in the case of purely earthen roads, it would be reasonable for District Boards to force pneumatic-tyred carts to use the cart *likh* for about a month towards the end of the monsoon wherever extensive earthwork is in progress. There is no doubt but that such carts make such roads practically impassable for motor traffic when under heavy repair. As there is not much carting during the monsoon, this occasional temporary restriction should cause no hardship to the drivers of pneumatic-tyred carts.

Lastly, there is the question of taxation.

In some parts of Assam, which is the only province where local boards tax carts, the fitting of pneumatic tyres is encouraged by taxing them at a lower rate; but the Municipalities in the rest of India follow no such policy of encouragement.

Before closing this Paper I would like to stress the fact that I am personally entirely disinterested in the manufacture of pneumatic tyre equipment. I strenuously advocate price control and, if necessary, the state manufacture of pneumatic tyre equipment (9).

The difficulty is that, whenever any member of this Roads Congress commences to advocate the use of pneumatic tyres, the strongly national non-technical individual suspects such member as being personally interested, either from motives of personal gain, or as the result of some sub-conscious desire to help the "foreigner" at the expense of the Indian national.

This gives me deep concern.

Could we not offer free membership to one or two influential members of the All India National Congress, the Muslim League, the Indian Union of Local Authorities, the Servants of India Society, and such strongly national bodies in the hope of getting these bodies represented as strongly as possible at our meetings ? This arrangement appears to be specially desirable when subjects like the present one, or ribbon development, safety-first layout, and such matters which are semi-technical, are under discussion.

There is not the slightest doubt that their delegates, having mixed with our members and formed their own conclusions, would advocate full support for the Indian Roads Congress which may then become more generally recognised for what it really is, a good servant of India.

And now it is hoped that members will speak on this Paper and complete the process of "unfolding" this problem. It is also hoped that such members will "make recommendations."

Let us not be discouraged by the knowledge that only the youngest of us can hope to see any substantial realisation of the low-cost road ideal. Most of us must be content with the thought that we have done our best, by drawing attention to the steel tyre, to make it at all possible for the coming generations to construct the low-cost road.

APPENDIX OR NOTES.

(1) *Mr. Churchill's suggestion :—"Brevity in Official Documents" Extract from "The Statesman" of dated August, 25, 1940.*

" The Premier in inviting his colleagues and members of the Civil Service to save everybody's time and energy by condensing official reports........says :—

"To do our work we all have to read a mass of papers. They are nearly always too long. This wastes time, while energy has to be spent in looking for essential points..............All should see that their reports are shorter, and should set out the main points in a series of short crisp paragraphs. If the reports rely on detailed analysis, some complicated factors, or on statistics, these should be set out in an appendix."

(2) *Extract of Resolution of the Indian Roads Congress dated 12th December, 1940.*

"This Congress, constituted by the leading highway engineers of the Governments and local bodies throughout India, and by the representatives of all the important highway construction and transportation interests

(c) Believes that progress in rural roads can be made by improving not only the road surface, but also the design and the loading of the vehicles that ply on them, and that the solution can be found without adversely affecting the economic condition of the villagers;

(d) Considers that the progress made in the provision of roads and bridges since the Report of the Road Development Committee has been wholly inadequate, owing chiefly to difficulties not foreseen and which could not be foreseen by that Committee;

(e) Considers that the time is ripe for a complete review of the whole position, and that such review is a matter of National urgency;

and to this end this Congress recommends to the Government of India that in order to prepare for an adequate and progressive road policy after the war, a Committee be appointed.

3. To examine how far the steel tyre is an obstacle to progress, and in what way that obstacle can best be overcome."

(3) *Low-cost road surface.*

A surface for moderate traffic, that will cost less than a hard pavement and yet be open to traffic, excluding steel-tyred traffic, all the year. This includes surfaces of stabilized earth gravel, crushed stone, *kankar* and murum that can be manipulated, and also thin tar or bitumen surfaces over a cheap base course.

The low-cost surface may be considered as a compromise between the "*kacha*" and the "*pucca*" surface. It might alternatively be called the "*kacha-pucca* surface."

(4) *The commercial or professional cart.*

That which works within and in the neighbourhood of towns, and in connection with mills, plantations, estates etc. in rural areas. Ownership is by single carts, or groups of carts by individuals or concerns. There is always a consideration for the carting, generally money.

(5) *The agricultural bullock cart.*

That which is individually owned by an agriculturist who pays land cess and who carts his own or his neighbour's produce from village to village, or village to market. Practically no money passes. The owner is without ready finance and, for the majority of the year, uses his bullocks for ploughing, or purposes other than carting.

(6) *Prejudice based on politics or lack of technical knowledge.*

(a) Mr. Gandhi in "Harijan" May, 28, and June, 4, 1938.

"Pneumatic types, which their advocates are so enthusiastic in recommending for use for bullock carts, are, even when they are manufactured in India, NOT SWADESHI in the sense that the "control, direction, and management either by a Managing Director or by Managing Agents" of the concerns manufacturing these tyres are NOT "in Indian hands". This in itself should be a paramount consideration for ruling out the use of these tyres for village carts. It might be yet another instance of foreign interests being fattened a the cost of the Indian masses."

Mr. Gandhi then goes on to point out that, with the extinction of the traditional trade of the wheel-wright and the impossibility of the artisans finding employment overseas, many will starve. He used the following very moving words :—

"Is even the little crumb of bread which they have got to-day to be snatched from their hands? Are they to be denied even the right to honest toil? There are obvious advantages, it is said, in the use of pneumatic tyres. Serious doubts have been expressed as to this. But supposing that there are advantages in the use of pneumatic tyres, at what cost in human misery are they to be purchased? The grim tragedy has been enacted in the case of many of our industries which have been wiped out of existence. Will it be enacted in this case also? Shall we be willing parties to the ruin of a section of our own countrymen? If not, it is up to us to resist the use of pneumatic tyres for bullock carts with all the strength that we can command."

It is natural that such a stirring appeal should influence many, and the following quotations are typical :—

(*b*) Madras Mail—August, 18, 1938.

"Dr. Kumarappa, the Secretary and Touring Propagandist of the All-India Village Industries Association, said that on his recommendation, the Parliamentary Secretary to the Minister for the Local Administration had sent circulars to all Municipal Councils and Local Boards, and these had passed resolutions in support of iron tyres. He added that rubber tyres imposed a heavier strain on animals and also caused greater damage to roads. Though rubber tyres were manufactured in India, he added, by buying them they would indirectly help foreign interests".

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(c) Extract of a Resolution passed by the Sub-Committee appointed by the Cawnpore Municipality—August, 8, 1939.

"The question of exemption in tax on vehicles fitted with pneumatic tyres is baseless......As regards comfort to animals, the load being doubled, the animals cannot be expected to be benefited. Taking into consideration the poor condition of India, the Board does not desire to destroy its few industries by inducing foreign ones. The introduction of pneumatic tyres will deprive thousands of labourers (black-smiths, carpenters etc.) of their bread......The Committee opines that the Board should support Indian industry and desire to extend them. It, therefore, recommends that no concession in tax on use of these tyres be allowed......"

Note:—To give them their due, the Cawnpore Municipality have recently sanctioned the increase of maximum allowable payload from 30 maunds fixed for ordinary bullock carts to 70 maunds for those fitted with pneumatic equipment.

(d) Bihar Local Bodies Conference—January, 1940. Presidential address of Maulvi Mohammad Sajjad, who had recently become Chairman, District Board, Saran.

"The present Boards are what, in common parlance, are called "Congress Boards." The ordinary people expect big things, almost revolutionary changes, from us. The sacred name of Congress is linked to the present Boards and it is in our power by our actions to raise the prestige of our national organisation ......An idea was entertained by some people that the introduction of pneumatic-tyred bullock carts would not adversely affect our roads but, from my own personal experience in my district, I have been led to the conclusion that these carts......are an even greater menace to our roads than the old type iron-tyred carts. I have found that such carts, themselves weighing as much as 14 maunds, carry loads up to at least 50 maunds each, which comes to more than 2 tons and, *as the carts, move on the roads slowly, the pressure of their weights on the road increases (approximately) by 50 per cent and thus each one of such carts may be taken to exert a pressure of a three ton load.*"

Since delivering this address, the Chairman of the Saran District Board has had the pneumatic-tyred bullock carts driven off the tolerably wide crests of the Saran District roads and some prosecutions have resulted. The District Officer and the Superintending Engineer advised against such a course.

(e) The remarks made by Mr. S. B. Joshi on Paper J-39 and reported in the proceedings of the Sixth Indian Roads Congress Vol. VI, will illustrate the suspicion of exploitation by foreign interests.

Many other instances of prejudice based on politics and lack of technical knowledge could be given.

(7) *Mr. T. Campbell Gray. Discussion on Paper J-39. Proceedings of the Indian Roads Congress Vol. VI, December, 1939.*

"In considering ways and means of overcoming the excessive damage done to roads, it has always seemed to me that, in recommending the immediate substitution of pneumatic tyres with elaborate steel shafts in ball bearings, we are advancing in too rapid a stride. I would, therefore, ask if it might not be better to aim at a gradual transition from the steel-tyred wheel to the pneumatic-tyred one by first encouraging the use of solid rubber tyres which might be fitted to the ordinary cart wheel, either by the inclusion of a suitable groove made when turning the wheel out to its finished diameter, or by cleats screwed on.

(8) *Darbhanga District Board. Extract from its proceedings dated March, 2, 1940.*

"Whereas our District Board Carriage roads are not wider than 15 feet and that a loaded pneumatic-tyred cart if running in series will considerably block the roadway so much so that the fast moving vehicle traffic have to wait for a considerable time till the carts make way for them, as also the carts though with pneumatic tyres have no spring and the damage to the road is equally heavy as is done by ordinary bullock carts. It is resolved that the pneumatic-tyred carts be not plied on the carriage road. Seconded by Babu Surat Jha and carried unanimously."

As a result of this, pneumatic tyred carts are now forced down into the cart *likh* more or less at ground level alongside the formation for the earth or brick-metalled crest.

(9) *Extract from Proceedings of the Indian Roads Congress Vol. VI Paper No. J-39 by Mr. W. L. Murrell.*

"In case it might be objected that the widespread adoption of the pneumatic tyre would be playing into the hands of private vested interests, it is suggested that, if local governments are capable of undertaking the supply of electricity and such national requirements on a large scale, they are easily capable of manufacturing and distributing at cost price pneumatic tyres for carts, the tyres being no less a national necessity than, say, water for irrigation. Besides this, it is doubtful whether private enterprise alone could meet what would be the demand for the tyres."

CORRESPONDENCE.

Comments by Mr. I. N. Mehta (Multan).

I have been trying at Multan that the professional cartmen should change from steel-tyred carts to pneumatic-tyred carts. The difficulties and prejudices, that stand in the way of the use of pneumatic-tyres, inspite of the preferential treatment, shown at Multan to the pneumatic tyres, are given below for the information of the Roads Congress.

As a first incentive to the use of pneumatic tyres, I suggested to the Multan Municipal Committee in March 1936, to exempt all carts fitted with pneumatic tyres from the payment of License Fee (Rs. 3/- per annum) and Wheel Tax (Rs. 3/- per annum). At that time the Committee considered my proposal impracticable but later on they saw my view-point and resolved in June 1937 that the carts fitted with pneumatic tyres be exempted from the payment of the License Fee and the Wheel Tax for 3 years. After the Resolution was passed, I tried to persuade several of the professional cartmen to change their carts promising them that more facilities will be granted. The initial cost of pneumatic tyres was considered by them prohibitive and they did not like to make use of the concession offered by the Committee. Later on, I issued the instructions that the contractors, who supply ballast and *bajri* on Municipal Roads, shall have to transport it by vehicles fitted with pneumatic tyres. The contractors used motor lorries for their transport and the desired result of getting pneumatic tyres fitted to some of the carts was not attained. I thought of another scheme to persuade the cartmen to use pneumatic tyres. I approached the Committee to allow the carts fitted with pneumatic tyres to carry loads one and a half times the load permissible under the bye-laws. This the Committee did and within six months of the Resolution of the Committee, about 10 per cent of the carts were fitted with pneumatic-tyres. There is a great prejudice in the minds of the cartmen that the tubes often get punctured. Moreover, they do not feel at home while driving these carts. They even fail to learn how to pump air in the tubes.

I also persuaded the Committee to fit some of the Municipal conservancy carts with pneumatic tyres. This was done and I found that the usual labour, engaged for drawing carts, was so much ignorant that they used to break pumps very often while pumping air in the tubes. Very often it was found that the pressure in one of the tubes was very much greater than in the other. They were given a little training but that did not help matters very much. Later on, an allowance was given to the lorry drivers to see that the pneumatic equipment of carts is kept in good condition. I must admit that the labour does not feel at home while using pneumatic-tyred carts and, that is why the contractors also feel shy of using pneumatic tyres. I asked some of them to have solid rubber fitted on their carts, as is done in the case of tongas. This they have done as the cost was from Rs. 20/- to Rs. 30/- and they seem to be satisfied except that they complain that the rubber does not last for more than 6 months. I think, the cartmen, who have one-bullock carts, can be easily persuaded to use solid rubber tyres if some kind of tyre is specially manufactured which would last for about a year or so with little additional cost. In a

two-bullock cart, the solid rubber tyres will wear out too soon and the pneumatic tyres are the only solution.

I have got one more suggestion to make and that is that we should approach the Society for the Prevention of Cruelty to Animals that they should encourage pneumatic tyres as the animals feel much more comfortable while plying pneumatic-tyred carts than iron-tyred ones. They may advance loan without interest for the purchase of pneumatic equipment, give prizes annually and do other things to encourage the use of pneumatic equipment.

Reply of Mr. W. L. Murrell, O.B.E., (Author), to the above Comments.

Mr. Mehta appears to be fortunate in having had good backing from the Multan Municipal Committee.

Doubtless, the most important point brought out by Mr. Mehta is that by far the most effective method of encouraging the pneumatic tyre is to allow carts fitted with such tyres to carry loads greater than those allowed to steel-tyred carts. Conversion of 10 per cent of the carts in the Municipality in six months speaks volumes.

It is suggested that contractors for Municipal road-metal should not get any concession for using motor trucks, especially, where there is a high percentage of water-bound milage. Carts with pneumatic tyres only should be given concessions, as motor trucks do a lot of damage to water-bound surfaces.

The difficulty of [illegible]on can be overcome by enlisting the aid of the petrol compar[illegible] in some cases, assist the good cause by getting their distri[illegible] give free air to pneumatic-tyred carts. Or it woul[illegible]ipality to lightly subsidise 2 or 3 air stations to give such free service.

Mr. Mehta's assertion, that solid rubber tyres wear more quickly than pneumatic tyres in two-animal carts, is interesting. This appears to be due to the side-to-side or yawing movement of the animals as they proceed. This movement causes the tyres to "screw-into" the road surface. The flexible walls of the pneumatic would take up a good deal of the screwing movement, and hence there would be less wear in the case of the pneumatic tyre. This point is for consideration when studying the proposed "compromise" types of tyres.

As regards approaching the Society for the Prevention of Cruelty to Animals with a view to getting that association to popularise the pneumatic tyre, this course is, unfortunately, not generally feasible. The difficulty is that the Association has to initiate legal prosecutions, and they must give nobody the chance to allege that they are financially interested in pneumatic tyres and that their real object in prosecuting is to force the carters to adopt such tyres.

Comments by Mr. P. V. Chance (Central Provinces and Berar).

A survey by the Agricultural Department showed that there are 11,25,848 carts in the Central Provinces. The annual cost of rubber tyres, including depreciation and maintenance, is not likely to be less than

Rs. 25/- per cart or Rs. 2·81 crores for the carts in the Central Provinces, a sum which is considerably more than half the total revenue from all sources. If 10 per cent of the carts are fitted with rubber tyres, the annual expenditure would be Rs. 28 lakhs. The cost of maintaining all the roads is Rs. 22.6 lakhs of which roughly one-third is spent on repairs to bridges and culverts, maintenance of bungalows, and miscellaneous repairs; and two-thirds, or say Rs. 15 lakhs, are spent on renewals of road surfaces.

It is obviously impossible that the cost of fitting carts with rubber tyres can be met from saving on road maintenance, at least in the Central Provinces. If there are provinces more favourably situated, it would be of interest to see calculations showing the financial advantages of fitting tyres and perhaps the author may supply them. Possibly the most continuously employed professional cartmen are those working for contractors and I agree with Mr. Murrell that contractors do not consider the fitting of rubber tyres to carts an economy. They are quick enough to adopt progressive methods in other directions. They will use lorries and will weigh up the relative advantages of petrol, diesel and charcoal-gas engines, but they will not put rubber tyres on carts because they do not think it will pay them, and I have no doubt they are right.

There are other directions in which progress on the improvement of roads is possible and I should be sorry to see the Roads Congress pin its faith only to rubber tyres. I do not desire to criticise the "compromise" tyres and "composite" wheels which the author has evolved. They have not been tried, and, as the author states that they are not suggested as serious rivals of the pneumatic-tyred cart with roller bearings, it is not clear why they should be tried.

Reply of Mr. W. L. Murrell, O.B.E., (Author), to the above Comments.

The last sentence of Mr. Chance's remarks clearly shows the rather peculiar attitude he has adopted.

When it was stated that the cart with the "compromise" tyre or "composite" wheel could not be considered as a serious rival of the cart with the pneumatic tyre and roller bearings, the average reader surely understood that the comparison was on the sole basis of excellence as a vehicle of transport, without regard to cost.

If Mr. Chance had read the whole of the paper carefully, he would have seen that the author had suggested the "compromise" and "composite" types for very extensive use indeed, *vide* the foot of page 67 and top of page 68.

I now continue the reply in the hope that my critic is not among those "who will not see."

Presumably, Mr. Chance, like several of us, places the professional carts at about 10 per-cent of the total number.

Whereas the example he takes assumes that all professional carts are to be converted to pneumatic equipment and roller bearings, I have

merely suggested that some of this 10 per cent should be converted, *vide* (*a*) at the foot of page 67.

Again, Mr. Chance should not have taken Rs. 25/- per cart, but the difference in cost of maintaining the pneumatic-tyred equipment and of maintaining steel-tyred equipment.

Mr. Chance's figure of Rs. 28 lakhs is, therefore, a very grave exaggeration.

But it is suggested that Mr. Chance has really missed the chief point of the matter.

The point is that the person, who uses the roads, should pay for them roughly in proportion to the damage he would do to them.

Mr. Chance states that Rs. 15 lakhs are spent on road surface renewals annually in the Central Provinces.

I stand to be corrected when I state that the professional carters pay comparatively very little of this Rs. 15 lakhs, and my contention is that if professional carts had the equipment, mentioned in para *a* (*i*), (*ii*), (*iii*) on pages 67-68 of the Paper, they would be paying a fair share of the 15 lakhs or of the reduced maintenance costs which would result from the abolition of the steel tyre.

I am afraid that I must disagree with Mr. Chance's assertion that contractors will not put rubber (pneumatic) tyres on carts because they do not think it will pay them. It is chiefly a question of finding the price of the equipment. Where carting is done systematically and the money for pneumatic equipment becomes available, conversion is fairly rapid. Mr. Mehta has stated an example. I could quote the case of dozens of concerns carting sugar cane with large fleets of pneumatic-tyred carts. I know of one fleet of over 70 such carts.

Comments by Mr. M. Gnana Mani (Tellicherry).

It is really a problem to suggest any modification for anything like the steel-tyred bullock cart which has evolved to its present design : but the fact, that we have a new model car every year since the time Henry Ford made his car, gives one the hope of attempting something better every day. The points, to be considered in connection with the modification of the existing design, are as below :—

1. The modification proposed should, as far as possible, be limited to the minimum so that it would not be too much for the cartman to change over to this design without interfering with the existing design.

2. The modification should be capable of being effected by the workman available in the village.

3. The materials proposed should be easily accessible to the villager.

4. The cartman should know that the proposed design is more advantageous to him.

5. Lastly, and the most important of all, the proposed design should contribute towards the improvement of the road-*rupee ratio which is the main object of* the Indian Roads Congress.

Let the above points be considered in relation to the proposed design, *vide* drawing facing page 77f :—

1. The proposed design is only an extension of that now used for the *jutka* wheels. The difference, however, is that the tyre for *jutka* wheel is obtainable in the market already rolled as such and the blacksmith just heats it and winds it round the rim of the wheel. Also, the overall width of the tyre is about two inches bent, as shown in the drawing, to receive the rubber treading, while four inches width is proposed for the bullock cart wheel.

2. Local enquiries have shown that the proposed section can be made by an average blacksmith by bending the ordinary steel plate of six inches by quarter of an inch section : but the making charges are reported to be nearly four times the charges for the existing type. These making charges can be reduced by supplying the blacksmith with the four inches wide section already rolled in the mills just as he is getting it for the *jutka* wheel tyres.

3. When the villager is getting a section for the *jutka*, there is no reason why a similar but a bigger-sized section cannot be made available for the bullock cart. The bitumen or molasses is easily available to the villager.

4. The whole success of the proposal revolves round this point; and it is a serious question how the cartman really gains in adopting this design. Two methods seem feasible. On page 73 of the Paper under discussion, it is stated that, in some parts, the fitting of pneumatic tyres is encouraged by taxing them at a lower rate. Perhaps the same procedure may be adopted in the case of the carts fitted with "compromise" tyres. The compensation to the Local Boards resulting from this loss may be made up in the shape of enhancement of road grants thus reducing the money to be spent by the Local Body. Again on page 68 of the Paper, it is stated that the producers of the pneumatic tyres claim that they are willing to supply them at the very *lowest* price as they believe that the wide spread use of such tyres will make possible a great milage of low cost roads thus increasing motor traffic generally. Under the circumstances, there seems no reason why it cannot be hoped that the producers of this "compromise" steel tyre will not be generous in reducing the cost of this section to the barest minimum, in view of the fact that more steel is required for bridging the streams towards which more grants will be

possible if the grants for the road maintenance proper can be reduced by designing a less harmful tyre for the bullock cart.

5. A glance at the drawing on the opposite page will show that the sharp cutting edge of the steel tyre is avoided by rounding the edges and filling it up with soft material. Also the bearing area is increased by hundred per cent and there is less scope for the earth roads to be cut up into deep tracks which make them so unfit. On the other hand, these "compromise" tyres cause an ironing effect on the earth roads surface. If the tyres can be good to the earth roads, they can certainly save the metalled roads also and the Road Engineer will have achieved much.

Reply of Mr. W. L. Murrell, O.B.E., (Author), to the above.

I suggest that Mr. Gnana Mani's opening sentence shows the attitude of mind we should all attempt to preserve and, in this connection, it may be observed that the proposed super-broad wooden tyre has already been called the "balloon wooden tyre".

Mr. Gnana Mani's design is certainly a contribution to the solution, and is very welcome.

The section, 6 inches by ¼ inch or even 6 inches by 3/16 inch, could be mass produced and put on the market just as in the case of the tyre for the *jutka* wheel, or it could possibly be made by a competent blacksmith. The skill, which many village blacksmiths exhibit, is surprising.

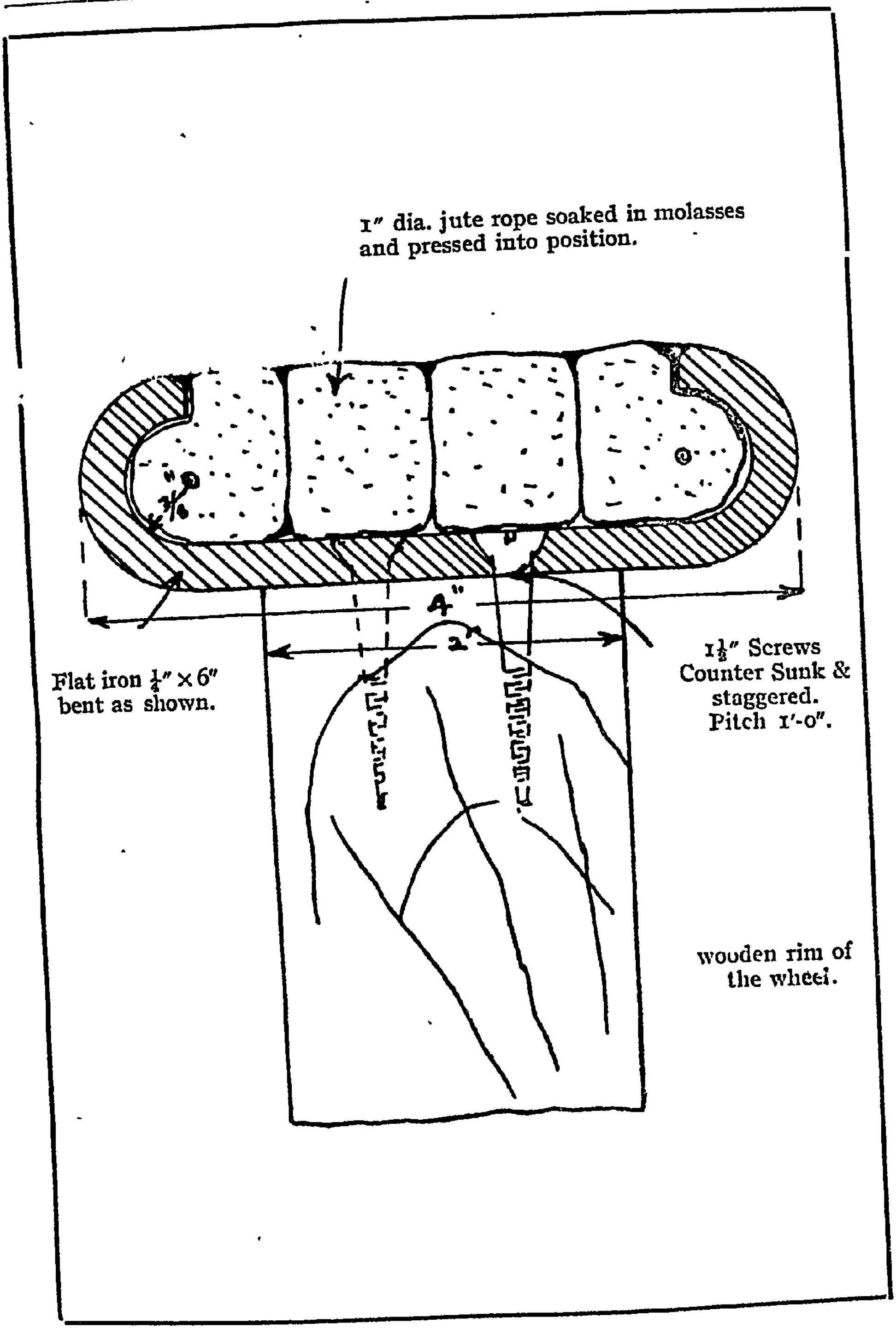
The increased cost of this tyre would not be so very great a disadvantage if it were given preferential taxation, or if its adoption were subsidised. The cost would be very small compared with that of pneumatic tyre equipment.

Rather a severe disadvantage would be its weight, there being three times the amount of steel, or about twice the amount if limited to 3/16 inch thickness.

Each impregnated rope would really need a flexible or springy wire core or something to keep it from coming out of the rim as the ropes would stretch considerably when subject to continual lateral pressure.

It would also be necessary to have some local authority to safeguard that the ropes are changed, not only for the sake of the road surface but also for the sake of the cart owner. If the ropes were to wear considerably, the curved edges would soon cut grooves in the road, and they would themselves wear thin and become distorted, thus necessitating expensive replacement.

It might, of course, be possible to give the worn ropes a coat of bitumen and ¼-inch chips, or some other treatments to make up for wear.


1" dia. jute rope soaked in molasses and pressed into position.
3/16"
4"
2"
Flat iron 1/4" × 6" bent as shown.
1 1/2" Screws Counter Sunk & staggered. Pitch 1'-0".
wooden rim of the wheel.

With a 3-inch felloe and 7 inches by 3/16 inch steel section, we could have a 5-inch tyre which would do well on earthen roads.

I do not think the design is suitable for bound macadam or surface-treated roads owing to the two curved metal edges which would quickly become proud on such surfaces and then, not only become damaged, but also inflict damage on the road.

Concluding remarks by Mr. W. L. Murrell, O.B E., (Author).

There have been a few developments as regards the "compromise" tyre since the Paper was written.

Enquiries were made from the rubber-tyre interests as to whether solid tyres could be built up on galvanised iron wire cores as shown in Plate I facing page 68, of the Paper, using country-made fabric and rubber solution. The Company was enthusiastic but too engaged with important war work to do the necessary detailed investigations. Besides this, the rubber solution would make the wheel rather expensive.

A sugar expert was consulted as to whether molasses could be used to give a sticky, plastic material for use with country-made fabric. Correspondence shows that, the difficulty is to get a truly non-soluble molasses compound. In this connection may be read the Paper "Experiments on the Manufacture of an Insoluble Road Composition from Molasses", Proceedings of the 5th Annual Convention (1936) of the Sugar Technologists' Association of India.

It is just possible that something may be done with a compound of compressed jute and resin; but this possibility has just come to my notice.

It is in the matter of the broad wooden or "balloon" wooden tyre that actual progress has been made.

The Indian Road Congress having assured assistance to the extent of Rs. 200/- for the actual construction and testing of broad wooden tyres, a start has been made on Type A, *vide* Plate III, at the end.

The idea is to use the ordinary wooden hub and spokes as turned out by the village cart builder, *vide* figure 5 Plate III.

Two flange rings, figure 3, are made by the village blacksmith and six pieces of wood for the tyre, figures 1 and 2, are made by the village carpenter, for each wheel.

The spokes are housed in notches cut in the six pieces of wood, and the wheel is held together by the two flange rings and bolts. It is really a very simple arrangement and far less complicated than the present wheel with its six sections of felloe, and 4 spoke-wedges and one dowel piece for each of the six sections, to say nothing of shrinking on the satanic steel tyre.

PLATE III

Variations are being tried, substituting small 3/16 inch angles *for the flat iron flange rings, with the idea of supporting the sides of* the tyre and so enabling the wooden tyre to be made thinner and lighter.

12 bolts instead of 18, and lighter bolts are to be tried with a view to saving in cost and weight.

The design in Plate III is for carts for the larger bullocks such as one sees in the United Provinces and north-west Bihar. For north-east Bihar and western Bengal, the external diameter of the flange rings would be 3'-6" or even 3'-0", the width of the tyre being reduced from 6 to $5\frac{1}{4}$, or even $4\frac{1}{2}$ inches, to suit the smaller bullocks in the latter areas.

It is natural to presume that the type of wood required for the wood tyre must be cheap, and it must be tough and resistent to wear, Hardness may indicate toughness but not invariably so—as is the case with road metals. Lightness of the wood is a consideration.

In North Bihar, *sissum* or sissoo is generally used.

Nevertheless, it is hoped to try a really light and cheap wood such as mango or simul.

We know that in the running of a grindstone with a steel axle in wooden bearings, the steel wears more quickly than the wood and it may be possible to apply this principle to the cart tyre.

A very soft wood tyre might be toughened considerably by making transverse saw cuts 1/4 inch deep round its periphery, and impregnating the wood with the correct bituminous compound. Or the periphery might be holed with many but shallow holes which would carry bituminous compound. The idea in either case is to make the tyre pick up and retain gritty material from the road, or given to it by hand, in the same way as the wood of the grindstone bearing picks up and retains the grit coming from the grindstone.

It is hoped that sample wheels which have undergone trials on different kinds of road surface, or at least photographs of the wheels, along with a description of the trials, may be put before the next meeting of the Roads Congress.

It has been suggested that testing might be done on the Test Track, but the comparatively sharp curvature of the ends of the track would play undue havoc with a wide flat tyre. There are very few roads where the ratio of length on sharp curve to length on straight is anything like so high as it is on the Test Track.

A point about this new type of "compromise" tyre is that it can be fitted to the ordinary cartwheel simply by cutting the felloe away and using two light flange rings.

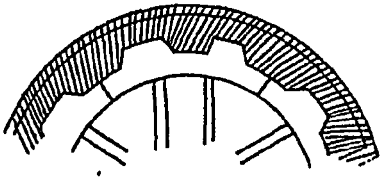


Fig. 1

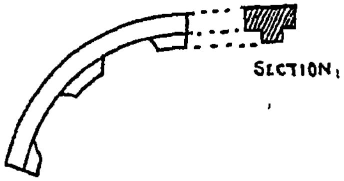


Fig. 2

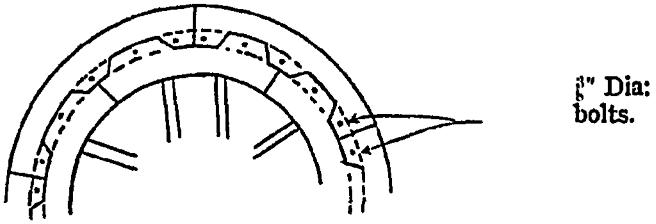


Fig. 3

Figure 1 shows hatched the steel tyre and portion of wooden felloe cut away from the ordinary bullock cart wheel.

Figure 2 shows a section of the wooden "balloon" tyre to be fitted. It has its central flange cut away to fit the remaining felloe shown in Figure 1. The village wheelwright can easily do this.

Figure 3 shows the assembly with two flange rings (shown dotted). These flange rings need only be very light as the joint between any two "balloon" tyre sections will break joint with the joint between any two felloe sections. The flange rings need, therefore, be only strong enough to keep the balloon sections on to the wheel, and in place laterally. They will not take any bending in the vertical plane.

So conversion is feasible utilising the maximum possible of the materials of the old wheel. Even the steel tyre could be cut, straightened, and then made into a flange ring.

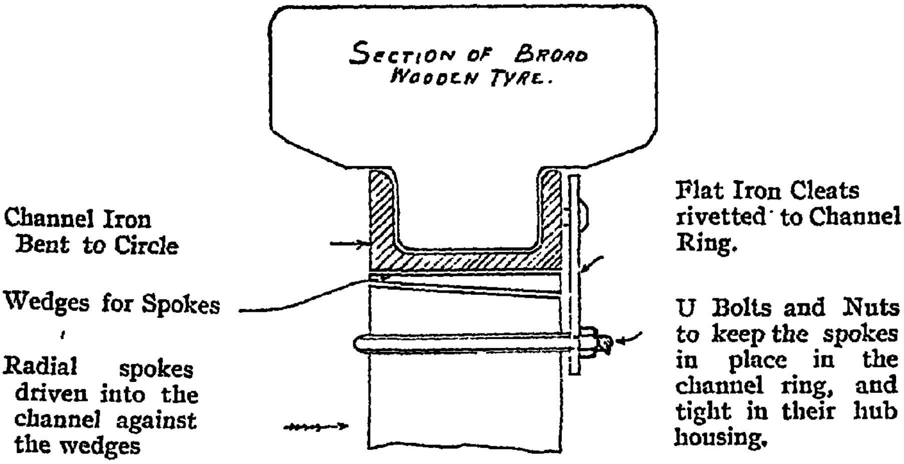
It should be mentioned that this particular type of tyre is applicable only to the type of wheel where the 8 or 12 spokes consist of 4 or 6 pieces of wood driven right through the hub, and more-or-less self-locking.

There is another type of wheel widely used on bullock carts in India. It closely resembles the European wheel where the spokes are truly radial and are driven into staggered, tapered holes, cut around the hub.

This type of wheel requires a steel band of some sort shrunk on, along with the felloe, to keep the spokes well home in their hub housings.

To achieve an equivalent arrangement, it will be necessary to place the sections of "balloon" wooden tyre, not between two flange rings as shown above, but between the flanges of a light steel channel bent to the same circle as the flange ring.

The spokes are to be driven sideways into the interior of the channel ring against wedges, and held there by 1/4 or 5/16 inch U bolts, as shown in the sketch below.



Finally, it is hoped that all members of the Indian Roads Congress realise that there will be a prize or honorarium of not less than Rs. 300/- for the current year, and for next year also, for the most practical design of bullock cart wheels or detachable rims to reduce the destructive effect of bullock carts on roads. The competition is open to the members of the Indian Roads Congress and to the public.

If these closing remarks on the Paper should prove of assistance to the prize winner for the current or for next year, he will be very welcome to them.

PAPER No. F-40.

PRIMERS, THEIR NATURE & USES.

By

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Introduction. In recent years Primers have attracted the attention of Road Engineers of India. There are, however, two schools of thought regarding the use of Primers—one which believes that Primers should be used universally, the other which believes that Primers are not at all necessary. These two opposing views are partly due to insufficient study of the exact nature of a Primer and its action on different classes of surfaces. The object of this paper is to describe Primers required for different conditions and to enumerate the circumstances under which the use of a Primer is an advantage.

Quite recently some experiments have been conducted with the principal types of primers available in India, and some observations have been recorded regarding their action under a particular set of conditions. It should be noted that this action will vary with different localities, road metal, nature of sub-soil, weather and climatic conditions, and that varying results will be obtained under different rates of application, blindage, time allowed for penetration and also from traffic conditions.

Composition of Primers. A primer should necessarily be asphalt or tar dissolved in a volatile solvent. By varying the percentage of asphalt or tar, primers of different viscosities are obtained. For different conditions, primers having different viscosity limits are suitable. Also by varying the solvent, primers having different curing properties are obtained.

As the object of the primer is to penetrate into the road base, only medium curing and slow curing cut-back asphalts should be used for this purpose. The relative merits of these two types will be dealt with later. Also by varying the base of the primer, the properties of primers having the same viscosity limits will be different. The choice of a primer depends on local conditions.

Necessity of Primers. Primers are generally required in cases where straight surface painting with a binder of high viscosity is not advisable. The function of the binder is to waterproof the underlying base and to hold the stone-chips of the cover coat firmly together. To develop adequate binding strength, the film of the binder, within recognized limits, should necessarily be thick. Usually straight asphalt or cut-back asphalt or tar of relatively high viscosity is used as a binder. None of these binders can penetrate into a waterbound macadam successfully, in view of

inherent high viscosity. On the other hand, they only form a mat on the surface.

Good hard stone metal, when properly consolidated, interlocks to form a firm base and the super-imposed load is efficiently transferred to the subgrade. Provided the stone metal is hydrophobic, *i.e.* it has more affinity for asphalt than for water, a carpet obtained by surface painting will strongly adhere to the base and will be quite satisfactory up to certain traffic conditions.

(1) With an inferior stone, slag, *kankar*, laterite, broken brick, etc., considerable crushing of the edges of individual pieces of aggregate takes place during consolidation. If the road surface is cleaned by removing all dust and particles of road metal, the mechanical interlock will be appreciably disturbed. If, on the other hand, these particles of crushed metal are not removed, they will be coated only on the top side by the binder application and will be a source of weakness to the surface-painted carpet. Under traffic, cracks will ultimately develop on the carpet due to poor support at points of contact of the metal of the base, through which water will enter, breaking the surface painting bond and weakening the water-bound macadam, thereby accelerating the destruction of the road.

Whereas, if a suitable primer is used, the loose particles will be thoroughly coated to the extent of the primer's penetration and after curing will provide a firmer support for the super-imposed carpet. Thus, the primer will strengthen the waterbound by virtue of its penetrative and binding properties.

(2) In the case of dusty aggregates, such as *kankar*, sandstone, laterite, etc., a primer can absorb the surface dust and can even penetrate into the metal itself. Application of a primer in such a case will result in better adhesion of the subsequent binder on to the metal of the base. Using a heavy binder, without priming, adhesion will be unsatisfactory and peeling of the carpet will most likely take place.

(3) In laying premixed carpets less than two inches in thickness, a tack-coat is generally specified. A primer would be a more suitable material than a heavy binder for the following reasons:—

(*a*) A primer by virtue of its penetration will increase the effective depth of the carpet, as the penetrated depth will be cemented to the carpet, and making the whole more resistant to the action of traffic.

(*b*) With a heavy binder on water-bound surface the rate of application would necessarily be heavy. Under traffic the surplus bitumen would be squeezed into the top carpet making it over-rich in bitumen. Corrugations and bleeding would ultimately occur. If, on the other hand, a primer is used for the tack-coat, the water-bound will absorb it, leaving a thin sticky film on the surface for tacking to the carpet to be laid.

(4) For roads having subsoil of high capillarity, application of a suitable primer is effective in checking the rise of subsoil water. For this purpose a very thin and slow curing primer should be used. Best results would be obtained by applying the primer on the sub-grade before laying the stone metal.

Reference may be made here to a method originally suggested by Mr. C.D.N. Meares for arresting subsoil moisture. The method, described below, is suitable for re-sectioning as well as for original construction of the water-bound course.

(*i*) Dress the base to proper grade and camber.

(*ii*) Spread the blinding material required to fill up the voids of the macadam, on the dressed base. Usually, 1/4 inch thickness is required for every inch thickness of the waterbound.

(*iii*) Add water and a slow-curing cut-back asphalt to make a slurry.

(*iv*) Now spread the metal and roll.

(*v*) Water and roll until the slurry works up to a point 1/2 inch below the surface.

(*vi*) Spread sand at 2 cubic feet per 100 square feet and roll.

(*vii*) Allow the road to dry for about a week.

(*viii*) Apply a medium curing primer cut-back asphalt and open the road to traffic after 12 to 24 hours.

(*ix*) Apply the second coat with a heavy binder within a period of 2 to 6 months.

Other cases where the use of a primer is an advantage, if not a necessity, are enumerated below :—

(5) In extremely cold climates, such as hill stations, or during winter months, original painting with the usual types of binders often results in heavy applications, due to increased viscosity or lowered penetration at lower temperature, followed by bleeding and corrugations in summer.

In such cases, a primer of low viscosity, used cold, can easily be spread at the desired rate with or without sand blindage. This would facilitate the spreading of the subsequent binder at the desired rate. Though the total amount of bitumen may be more than that for a single application of a binder, yet there should not be any bleeding, as the water-bound base would absorb most of the primer applied.

(6) In the case of gravel roads, there is not the same mechanical interlock as with water-bound stone metal. In surface painting such roads, if vigorous cleaning is done before hand, the gravel particles will work loose and the painted carpet will lie over a rocking bed in

extreme cases. The correct way seems to bond up the gravel base by impregnating the blindage with a primer, and then to surface-paint with a heavy binder.

(7) For roads where segregation of bullock cart traffic is possible, as in North Bihar or Bengal Duars, application of primers alone will be adequate, economical and effective for carriage-ways for motor and other pneumatic tyred vehicles. Sand, cinder or road-side dust containing not more than 20 per cent 200 mesh particles, may be used for blinding the primer. If the dust consists only of clay or silt, sand or cinders, preferably sand should be used.

(8) In cases of local bodies, whose funds are very limited, primers may enable the improvement to be carried on by stages, that is to say, the road may be given a priming coat using slightly larger quantities than usual, in one financial. year, and by laying the wearing course using a heavy binder and stone chips during the next financial year.

Classification. A primer may have an asphalt or tar base. Asphalt primers are necessarily cut-back asphalts. According to the revised specifications for cut-back asphalts adopted by the Asphalt Institute on December 13, 1939, and published in the Institute's Construction Series No. 51* of January 1, 1940, the following grades are recommended for use as primers :

" Tightly bonded surface	MC0
" Loosely bonded fine-grained surfaces ..	MC1
" Loosely bonded coarse-grained surfaces ..	MC2"

It may be noted that all the cut-back asphalts recommended by the Institute are medium-curing. The distillation ranges in the new specifications for MC materials are given in the graph on the next page.

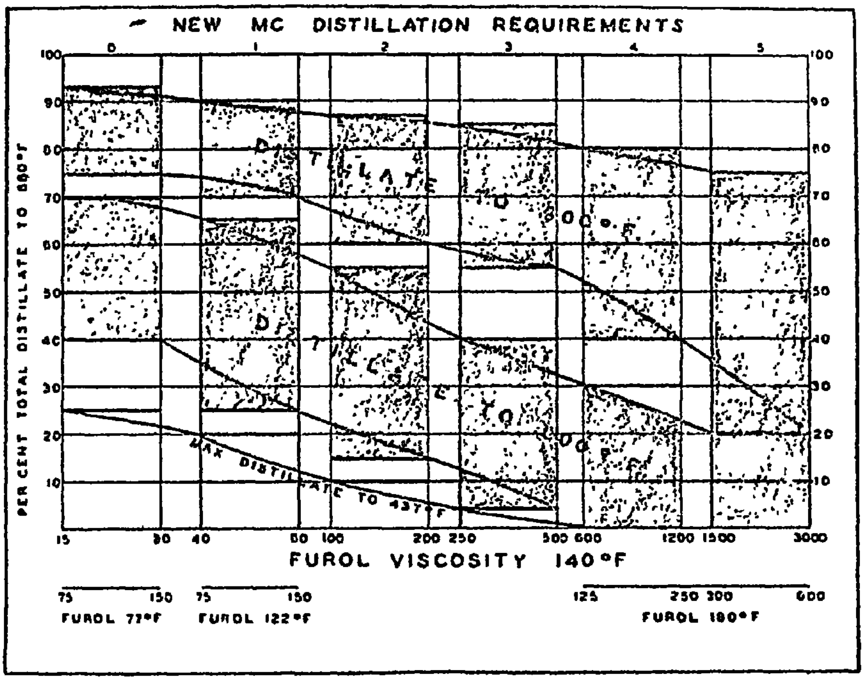
The rate at which a certain cut-back asphalt will cure, when applied on the road, is indicated by its distillation test. A cut-back asphalt which on distillation yields a high percentage of distillate at a relatively low temperature will cure or set more rapidly than one which would yield less quantity of distillate at that particular temperature. Again, a cut-back which yields a higher percentage of distillate at a relatively high temperature will be slower curing than that which would yield less quantity of distillate at the same temperature.

It has, however, been found that the distillation test does not indicate as closely as it should, the rate of curing under actual road conditions. Yet it is the best available means at present.

Low viscosity road tar is sometimes used as a primer. For a recent experiment with cold primers conducted by Mr. W.L. Murrell, Superintending Engineer, Bihar, Cold Tar Primers have been manufactured and used, probably for the first time in India. The report on the investigation of the

* Indian Roads Congress Library Catalogue No. IRC 111 (k).

behaviour of this and other cold primers will, it is believed, be included in the Report of the Technical Sub-Committee to the Council.



Some Engineers are in favour of using road oils for priming purposes. But, the objection to their use as such may be evident from their composition and the method of their manufacture. As I have already pointed out at the last session of the Congress, Road Oil or Residual Oil is obtained from fractional distillation of crude petroleum or crude oil, as it is commonly called, after the lighter fractions have been removed. It is, therefore, a combination of asphalt and heavy oil which is non-volatile at ordinary temperature, whereas, cut-back asphalt primers are manufactured by dissolving asphalt principally in light volatile solvents. It may, therefore, be appreciated that residual oils are necessarily slower-curing materials than cut-back asphalt primers. Also, they cannot penetrate as deep as a medium curing cut-back asphalt, in view of the higher viscosity of the heavy residual oil contained in them.

When a cut-back primer is applied on the road surface, it readily penetrates, depositing its asphaltic contents almost evenly throughout the penetrated depth, the volatiles being absorbed by the underlying fines.

The evenness of penetration has been noted upon taking up samples after treatment for test and is also shewn from laboratory tests, mentioned hereafter, carried out by Mr. W. H. Foushee, Jr., Bituminous Engineer, North Carolina State Highway Commission, U.S.A..

With slow curing materials, such as road oils or residual oils, there is little evidence of differential absorption and the result is the formation

of a somewhat soft or spongy layer of treated material on the surface. In the opinion of Mr. W. H. Wood, Engineer of Material and Tests, Texas Highway Department, U.S.A., "This spongy layer defeats the function of the primer which was to harden the surface as well as to bind it together," *vide* his paper presented at Eleventh National Asphalt Conference, Memphis, U. S. A., December 1937, Published by the Asphalt Institute, New York.

In view of its containing a relatively high percentage of heavy oils, a road tar would behave in the same way as the road oil, but the lighter oils in it would carry a certain percentage of bitumen into the road. The results with cold tar primers are not yet known.

Characteristics. As regards characteristics and action of primers, I believe the following comments by Mr. W. H. Foushee, Jr., *Bituminous Engineer, North Carolina State Highway Commission, U. S. A., will be of interest:—

"A prime material should possess satisfactory penetrating and bonding qualities, act as a seal and at the same time adhere to the next application of bitumen so as to form a homogeneous mat.

For a prime material we have found that asphalt base stock mixed with proper solvents answers the purpose. We have also found that the asphalt is carried by the solvent to the extreme depth of penetration which tends to strengthen the base and give it more flexibility as is desired in low cost pavements.

In order to prove this theory, experimental tests were made by our Chemical Laboratory on various types of soils from active projects. The soils used in this work had an average clay content of thirtythree (33) per cent and approximately seven (7) per cent moisture. Care was taken to approximate the conditions encountered on construction as nearly as possible. Uniform pressure was placed on test samples in accurately measured moulds and asphalt prime was applied at approximate rate of one-third of a gallon (U. S. A.) per square yard (approximately 3 Imperial gallons or 30 pounds per 100 square feet Author's Note).

After six days the samples were examined and the penetration was found to be very uniform having reached a depth of six tenths (0·6) of an inch. Careful samples were taken from top three tenths (0·3) of an inch and from the bottom three tenths of an inch and bituminous contents determined by extraction with CS_2 and by ignition. Deductions were made for natural loss on ignition of uncoated material. It was found that the average bituminous content was as follow:—

By extraction with CS_2 Top layer	3·67%
By extraction with CS_2 — Bottom layer	3·31%
By ignition—Top layer	3·33%
By ignition—Bottom layer	2·98%
Solid Asphalt left after removal of CS_2 solvent—Top layer	2·03
Solid Asphalt left after removal of CS_2 solvent - Bottom layer	2·37

From this data it is obvious that the asphalt is carried to the full depth of penetration."

Treatments. (1) For water-bound macadam, an application of 25-30 pounds (2·5 to 3 Imperial gallons) per 100 square feet should be recommended, though it is possible to apply primers at much lower rates. But, inadequate priming is inadvisable for the following reasons :—

* *Vide* Paper presented at Tenth Annual Asphalt Paving Conference, New Orleans, U. S. A., December 1932, Published by the Asphalt Institute, New York.

(a) With insufficient primer the required depth of penetration cannot be obtained. The requisite strengthening of the water-bound and proper anchorage of the wearing course would, therefore, not develop.

(b) At a fixed rate of application of the binder for the wearing course more of this will be taken up to cover the base treated with inadequate quantity of primer, and thus the quantity of binder required to hold the stone-chips cover-coat interlocked would be inadequate, leading possibly to disruption of the wearing course under traffic.

The recent tests carried on at the Government Test Track, Calcutta, bear out this argument. The particulars of these tests, it is believed, may be included in the report of the Technical Sub-Committee to the Council of the Congress.

(2) For Clay-gravel road, the following treatment which was used in South Carolina, (U.S.A.), should be satisfactory:—

"The road selected for this experiment was clay-gravel surfacing having a clay content of approximately thirty per cent. The existing surface was thoroughly cleaned of loose particles and dust for the entire width of treatment by sweeping with a revolving broom supplemented with hand brooms. After the surface was thoroughly cleaned and showed no signs of free moisture, an application of asphalt prime was applied at the rate of one-third of a gallon per square yard (*approximately 3 Imperial gallons or 30 pounds per 100 square feet, Author's Note*). I noticed in particular the penetrating qualities of the asphalt—within two hours after first load had been poured penetration of from one-eighth to one-half of an inch was encountered.

The prime was allowed to dry in from three to fortyeight hours depending on the character of soils and weather conditions. Generally, we let the prime dry in about five hours at which time we could drive over it without same picking up. On this phase of the work we found that the asphalt prime is advantageous in not slowing up next application.

The prime was followed by an application of heavy asphalt cut-back having a base of eightyfive to one hundred penetration and Furol viscosity of from 220 to 280 at 200°F. This application was followed with an application of local washed sand gravel ranging in size from one inch down at the rate of thirtyfive to forty pounds to the square yard. After the application of washed gravel had been uniformly spread and dragged with a broom-drag, it was thoroughly rolled with a 5-ton roller until all gravel had embedded in the asphalt. Traffic was allowed on this project within two to three days after it had been completed. The broom-drag was kept on sections that had not entirely set to keep the gravel cover uniformly distributed."

Recently, the author treated a moorum (which is similar to clay-gravel) surfaced road in Chaibassa with a medium curing cut-back asphalt and noticed that the penetration was over one-half inch with application at the rate of thirty pounds (3 gallons) per 100 square feet. The seal coat was applied with a heavier cut-back asphalt blinded with a mixture of two cubic feet of screened moorum and one cubic foot of sand per 100 square feet. No rolling was done and the road was opened to traffic after a week. The results so far are encouraging. Further details about this work may be available from the District Engineer, Chaibassa, who was present throughout the experiment and has kept careful record of the treatment and observations.

I have so far discussed the action of primers on water-bound roads, for which purpose these are principally used. But certain cut-back asphalt primers have also been used successfully on bitumenized road surfaces especially on old hard and polished ones. In view of their penetrative qualities, the primers act as a reviver and afford a tacking medium for the subsequent repaint. In laying premix carpets over a painted surface a cut-back also has its usefulness in providing such a tacking medium.

In conclusion, I would like to state that the object of this paper has been to place before the Congress some information of work in India and elsewhere regarding the uses of primers and to initiate discussions on this important subject. Though I have mentioned road tars and cold tar primers, I have confined my paper mostly to asphalt primers for obvious reasons. I hope that some other member of the Indian Roads Congress will come forward with a paper or further detailed notes on the uses of Tar Primers to supplement this paper.

PAPER No. G—40

SEVOKE BRIDGE

BY

JOHN CHAMBERS, O.B.E., M.C., A.M.I.C.E., I.S.E.,
Superintending Engineer, Darjeeling.

General.—The Sevoke river which is a typical hill stream in that its waters rise in the space of an hour from a few inches to a raging torrent of feet has taken its toll of more than one road bridge. In 1912-13 the railway up the Teesta Valley was constructed and the stream of the Sevoke river must have followed along a different alignment from that of the present, for it takes almost a right angle turn to pass under the railway bridge. As events turned out, it was unfortunate that the stream was allowed to change its course in the way it did.

A number of road bridges across the Sevoke have been washed away due to the erosion of the Teesta and to exceptional floods in the Sevoke. With the development of road communication, the necessity of permanent crossing became more urgent. So, in the year 1932, a proposal to build a low level causeway across the Sevoke, about 100 feet below the railway bridge, was submitted to Government. This was in the end considered to be unsuitable and it was decided to construct a bridge of 100 feet span (*i.e.* with a clear waterway equal to the railway bridge). As funds were limited, it was decided to construct a fixed arch, this being about the cheapest type of construction for large spans, assuming, of course, that the foundations of the arch could be shallow and that there existed necessary protection upstream to keep the stream in its then position.

The road bridge was completed in 1934. On the night between the sixth and the seventh July 1937, a cloud burst occurred and the recorded rainfall during the night was 18 inches. This was a minimum value as the rain gauge had overflowed. The stream, having changed direction, impinged on to the Sevoke abutment of the railway bridge causing its collapse. With this collapse the railway girders fell and acted as a further deflector to the main stream. This deflection sent the main stream behind the arch abutment of the Public Works Department bridge producing deep scour and consequent yielding of the abutment and failure of the arch. The author admits that the choice of type was unfortunate, as, had the reactions been vertical, the road bank would have been breached but the bridge would have escaped damage. It must be remembered, however, that the railway bridge had been in that position for 25 years.

After the collapse, the question of re-bridging the Sevoke was taken up and various suggestions were put forward. In order to determine the best position for a bridge across the Sevoke, an extensive survey was

undertaken. From this it was seen that the natural opening at Sevoke was the only place for a bridge as the stream opened out above this natural gut and formed a large flat delta. This survey also showed that it was out of the question to go upstream to find a narrow channel and so it was decided to build about 400 feet above the railway bridge. This decision was further influenced by the fact that the Teesta river was already heavily eroding its right bank so that the question of bridging below the railway bridge would have brought the bridge site far too close to this river.

The author was asked to submit a scheme for a bridge and drawing No. 5 shows his proposal.

This type of bridge, entirely novel to this country, which was at first received with some doubt, was finally decided on.

The following are the points to be considered when bridging a stream of this type:—

(1) The stream must be stabilized.

(2) Floatation of timber must be stopped as far as possible.

(3) Cheapness as regards both cost of construction and maintenance must be aimed at.

As regards (1), the tendency of the river was to have a cross-fall towards the opening in the railway embankment. This naturally produced a deep gut along the edge of the forest causing trees to fall and thus producing further trouble.

When work was commenced, it was seen that the cross-fall was about 7 feet towards the Sevoke side. In order to correct this, a reinforced coffer-dam (see drawing No. 7) was sunk along the entire width of the stream. Unfortunately the foundation work could not be completed before the rains started.

An early flood (about 8 feet deep in the main channel) brought down large trees, some of which actually came to rest on top of the collapsed arch bridge immediately below the railway bridge. Once the flood subsided, it was essential to take in hand the necessary training works as the tendency of the stream was to outflank the concrete foundations and to cut through the new embankment. Once the coffer-dam foundation was closed and the approaches protected, the river could not form a deep gut and, consequently, stabilization of the river could then be commenced.

As regards (2), floatation could not occur without sufficient depth of water. This point was clearly demonstrated as after the first 2 or 3 floods, no drift timber of any kind was brought down the river.

As regards (3), details regarding cost will be given later, but it will be obvious that a series of small spans, where form-work

can be standardized, is bound to be cheaper than large spans with expensive foundations.

CONSTRUCTION.

In order to speed up construction, steel form-work, sufficient for two 30 feet lengths of coffer-dam were purchased, (see figure 1).

As the total length of the coffer-dam was 300 feet, it was decided to sink in sections of 30 feet leaving a gap of 10 feet between sections, which was filled in after the adjoining sections had been sunk to the correct depth, (see figure 2).

In order to protect the concrete against corrosive action, all faces of the coffer-dams were coated with bitumen before commencing sinking.

De-watering was carried out by portable centrifugal pumps driven by Lister diesel engines. The pumps had a joint capacity of about 1,00,000 gallons per hour and they had to work full bore in order to keep down the water when closing the gap between two sections. Although the surface flow was small, the under-ground flow was very large and considerable trouble was experienced in keeping the water level below the bottom of the coffer-dam. The sinking gave trouble due to submerged trees, large boulders etc. (see figure 3).

Once the coffer-dam had been sunk, the compartments were filled with sand and gravel, well watered and rammed. After this 3 inches of weak concrete was placed on top of the fill so as to give a clean surface on which to erect the reinforcement for the base of the culvert, (see figure 4).

Immediately the base had been cast, steel forms for vertical members of bridge were placed in position, (see figure 5). The forms were stripped after 24 hours, re-erected and filled with concrete. Owing to the late start, it was not possible to get the complete base slab finished and consequently there was a gap towards the centre which meant that the base at this point was 9 inches lower than the remainder.

These figures clearly show that the stream is tending to stabilize, as it is flowing almost across the full length of the coffer-dam. At this stage, the main stream was flowing along the Sevoke bank and protective works had to be carried up stream for about half a mile in order to protect the bank.

The protective works required considerable attention and, consequently, progress on the bridge proper was delayed. Once the stream had been more or less stabilized, work was re-commenced, the walls being erected on the already completed bases and at a later stage, the top slab was also completed, (see figure 10).

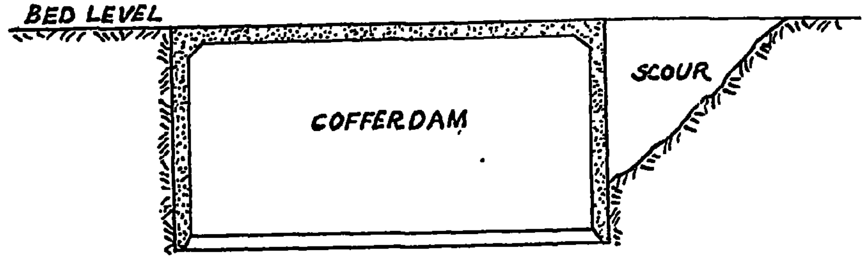


FIG. 11

During high floods, scour along the face of the coffer-dam occurred on the down stream side, this was immediately filled up with boulders to prevent the foundation of the coffer-dam from being exposed. It was seen that the maximum depth of scour was approximately equal to the height of water above the base slab at that point. The maximum scour was very local and quickly died away. Fig. 11 shows a cross-section of a typical scour.

It was also noticed that the boulders were moved when the stream was in high flood. In order to prevent this the top foot of boulders were placed in wire and at a later date covered or rather the voids filled in with weak concrete so as to keep the wire in position and also to some extent to prevent corrosion. Fig. 11*a* shows the protection against scour on the down stream face of the coffer-dam.

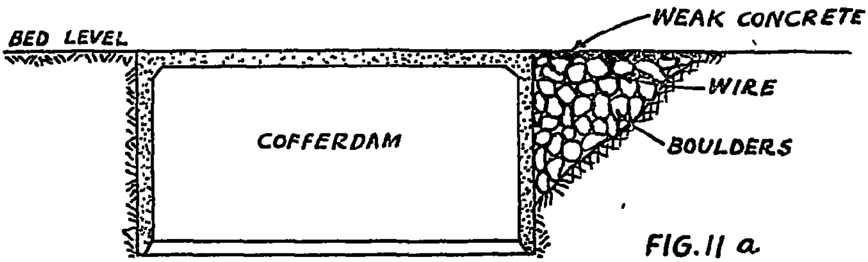


FIG. 11 a.

GENERAL DESCRIPTION.

The bridge is a reinforced concrete framed structure resting on and connected to a reinforced concrete coffer-dam. Total length of the bridge is 330 feet, each span being 10 feet. It is designed to carry two lines of traffic, the distance between wheel guards being 18 feet. The bridge runs on to a hill-side cutting at Siliguri end, and on the other end is an earth embankment. To reduce the cost of cutting and embankment, the bridge is made on a grade of 1 in 30 down from Siliguri end. Expansion joints on top slab are provided at each 110 feet interval to allow for temperature variation. Drain holes at intervals through the top slab at the wheel guard edge and a 2 inches cross camber to the road surface effect the efficient drainage of rain water. 3 feet high pipe railings with Reinforced Concrete pillars are provided throughout the bridge.

COFFER DAM.

The coffer-dam, which runs throughout the length of the bridge, is 10 feet deep and consists of two walls 20 feet apart connected at every 10 feet by cross walls. All the vertical walls of coffer-dam are 9 inches thick with cutting edges at bottom. Weak concrete is provided over the filling of coffer-dam. Over this, rests the bottom slab of the bridge proper. Reinforcements used are mostly 3/8 inch round bars, which continued from coffer-dam to the bottom slab and vertical wall of the bridge proper, in order to effect good bonding between the superstructure and the substructure. In case any settlement occurs in the foundation due to scour etc., walls of the coffer-dam will act as 10 feet deep beams and carry the superstructure. For this reason, all these walls are provided with requisite amount of top and bottom reinforcement and properly stirruped.

BRIDGE.

The structure is a Reinforced Concrete rigid frame consisting of 33 ten feet spans. All the members of the frame are made 9 inches thick, so that the moment of inertia of the members is constant. The top, bottom and vertical slabs constitute the different members and to ensure rigidity of joints, 1′×1′ haunches are provided to these slabs at every joint. The length of vertical members varies from 25 feet to 15 feet, the lengths of top and bottom members are constant and equal to 10 feet each. At each expansion joint, the slabs on both sides of the joint are made free to slide on top of column head. The bearing on top of the column head consists of a raised ridge made of cement mortar and the space between and the joint in slab is filled with bitumen and sand in the proportion of 2:1 to act as shuttering and to allow movement of slab.

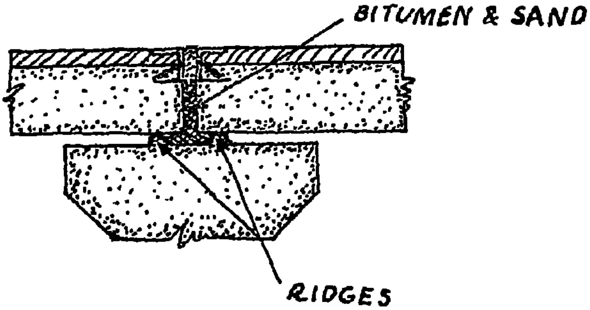


Fig. 13

In the design, the fixed points of the frame and different distribution factors are calculated according to the method given by "Suter". The Bending Moment diagrams are drawn in the ordinary way, typical Bending

Moment diagrams and the distributions for concentrated load as well as for uniformly distributed load are given in Drawing No. 3.

The following stresses are considered in the design :—

(1) Stresses due to dead load of the structure.

(2) Maximum stresses due to Live Load. (Either a ten-ton Steam Road Roller or a line of 6-ton lorries, whichever produces maximum effect).

(3) Stresses due to variation in temperature.

(4) Stresses developed due to braking effect of vehicular traffic.

At each section, these various stresses are combined to give maximum effect and designed for the same. To avoid excessive horizontal thrust of earth at both ends of the bridge, the bottom slab is made inclined at an angle of 45 degrees to the horizontal. (The angle of repose of earth is taken to be 45 degrees). Therefore, stresses due to earth pressure are not taken into account. The top and bottom members are designed for simple bending, while vertical members are designed for combined bending and thrust.

The road surface consists of a 2 inches wearing course over 1/4 inch Bitumen laid over the top slab. Wheel-guards are made of Reinforced Concrete and the railing consists of 2 rows of 2-inch pipes running through Reinforced Concrete pillars at intervals. To prevent abrasion of the bottom slab by flowing sand, gravel and boulders, a 2-inch wearing course is provided on top of the bottom slab throughout the bridge.

SPECIFICATION

Steel :—Mild steel tested to British Standard Specifications allowable stress = 16,000 pounds per square inch.

Structural concrete :—Crushing strength at 28 days for reinforced concrete work (average of 3 specimens-12 inch high and 6 inch diameter) = 3500 pounds per square inch.

Wearing course :—Crushing strength at 28 days (average of 3 specimens-12 inch high and 6 inch diameter) = 4000 pounds per square inch.

OTHER DETAILS

The cost per squa[illegible] of [illegible]vation area (be[illegible]ngs with Reinforced and the bottom of the [illegible] [illegible] bridge.

Figure 1.

Showing the river bed dressed to water level. The shuttering for the first coffer-dam is being placed in position.

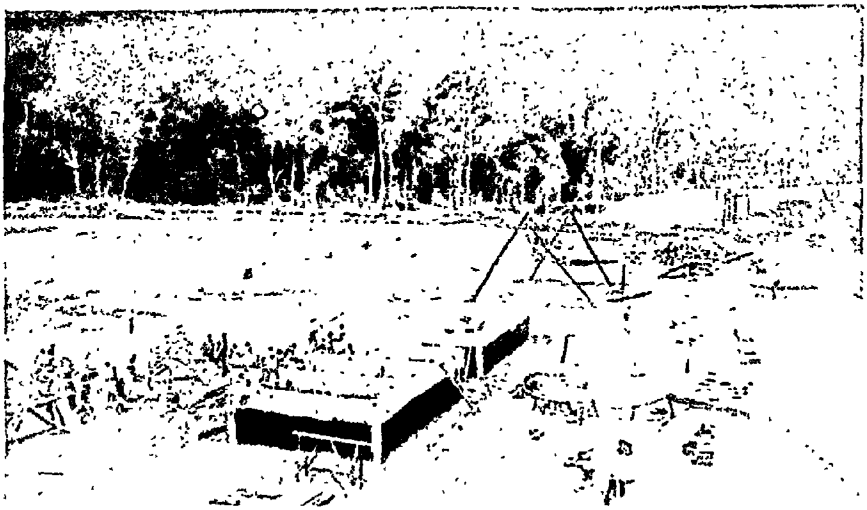


Figure 2.

Showing one section sunk and two others in the process of being sunk.

Figure 3.

Giving some idea of the type of soil through which the coffer-dams had to be sunk.

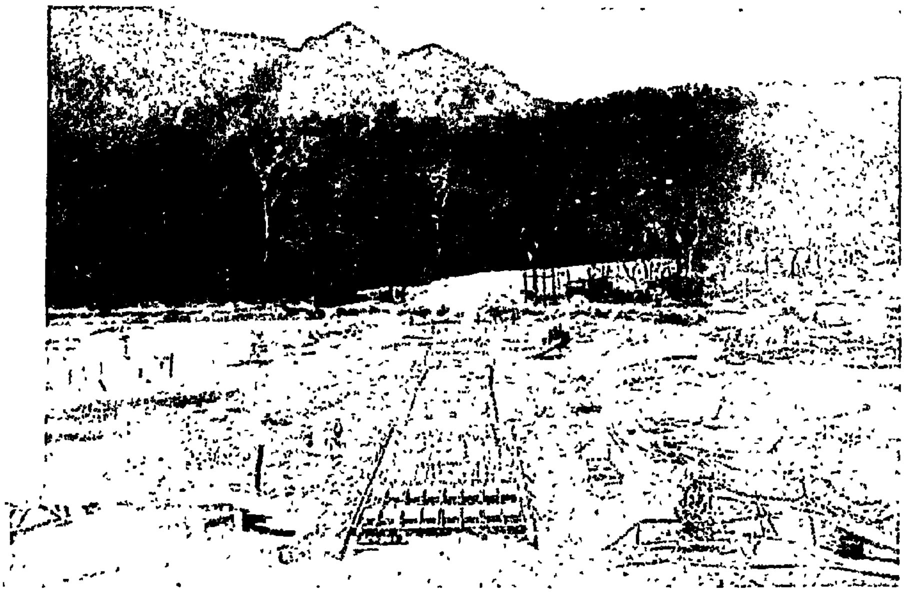


Figure 4.

[illegible] 3 inches of [illegible] crete placed on top of the fill to get a [illegible] surface [illegible] the base of the [illegible]ulvert.

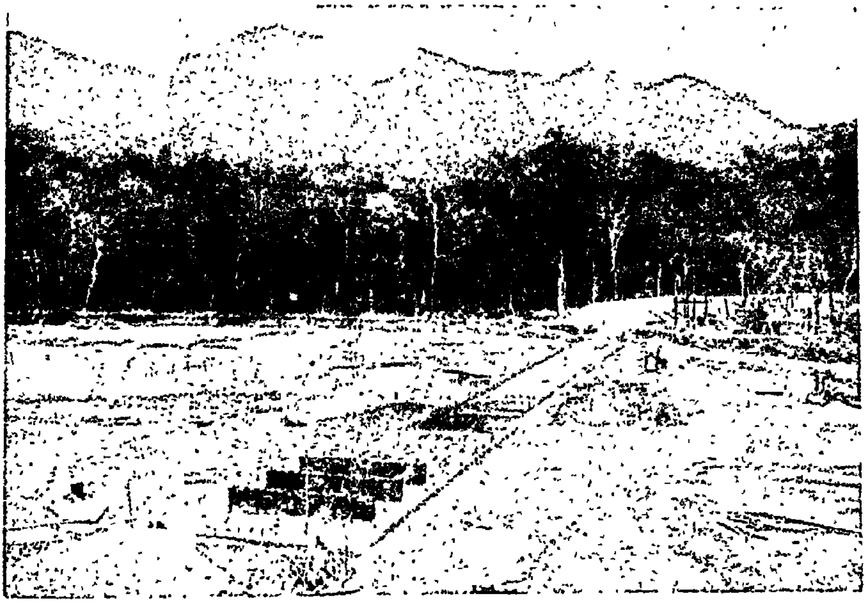


Figure 5

Immediately the base had been cast, steel forms for vertical members of the bridge were placed in position.

Showing [illegible] after the first flood. Notice the very [illegible] ought down and also the [illegible]

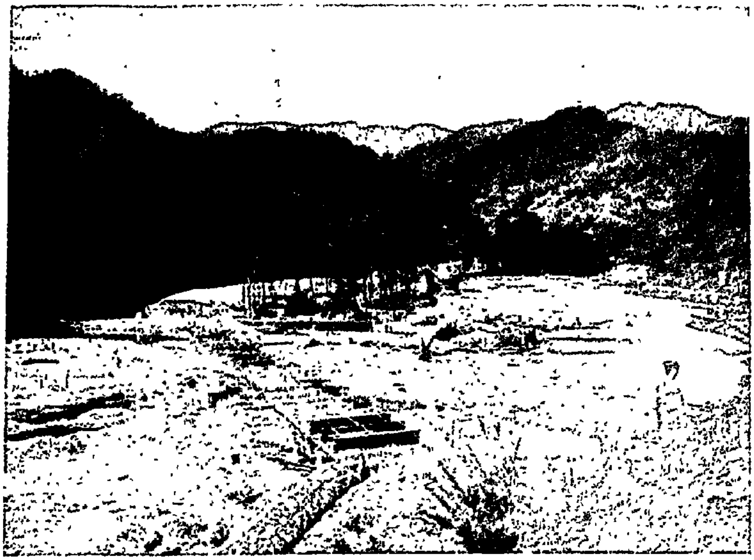


Figure 7.
Showing a sausage to protect the approach to the bridge.

Figure 8.
After the first flood, protective works (sausages, 8 feet diameter, filled with boulders) were placed to protect the approaches to the bridge.

Figure 9.

After the next flood, the river changed its course and the main stream ran along the Siliguri bank. As this bank is very low, protective works were considered necessary and a sausage was placed at *A*.

Figure 10.
Showing the completed top slab.

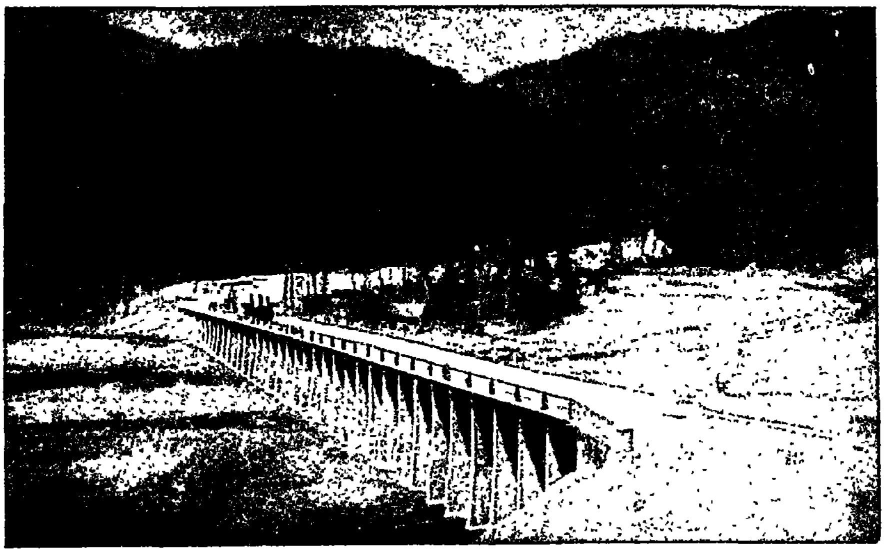


Figure 14.
Giving a view of the completed bridge.

Figure 15.
Showing the completed bridge in elevation.

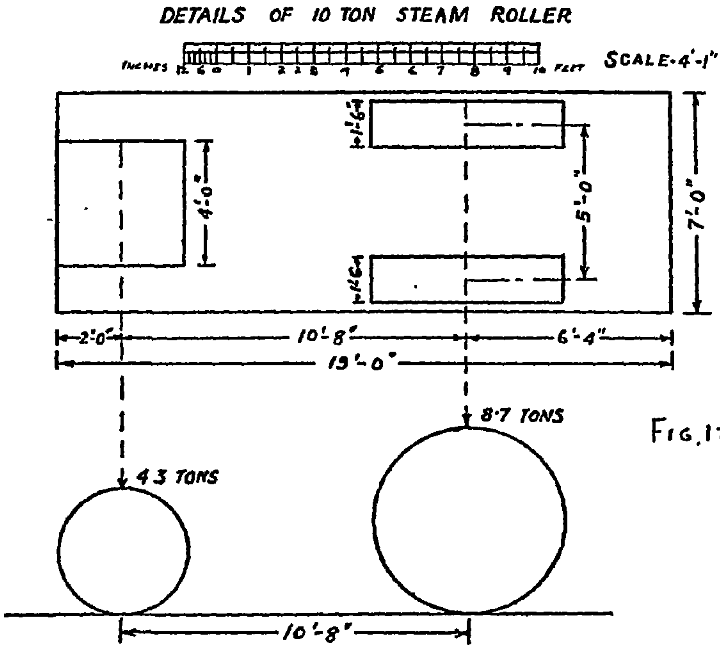

DETAILS OF 10 TON STEAM ROLLER
SCALE-4'-1"
4'-0"
5'-0"
7'-0"
2'-0"
10'-8"
6'-4"
13'-0"
8·7 TONS
4·3 TONS
10'-8"

FIG. 12

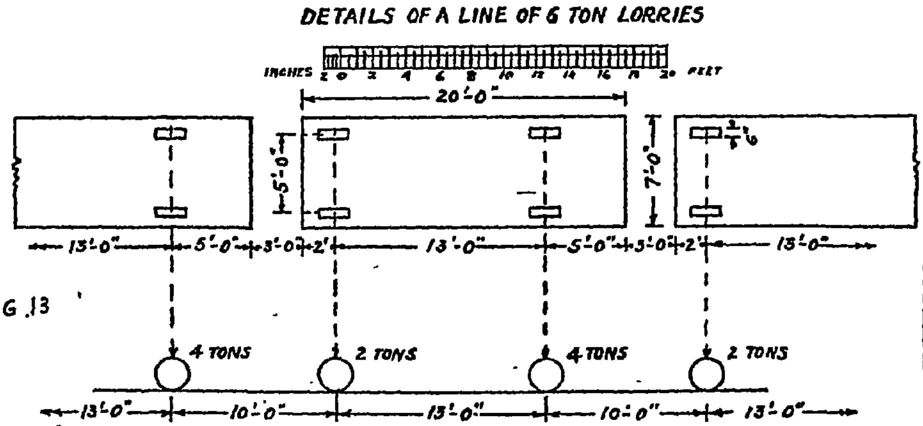

DETAILS OF A LINE OF 6 TON LORRIES
20'-0"
5'-0"
7'-0"
4 TONS
2 TONS
4 TONS
2 TONS

FIG. 13

DESIGN.

NOTATIONS.

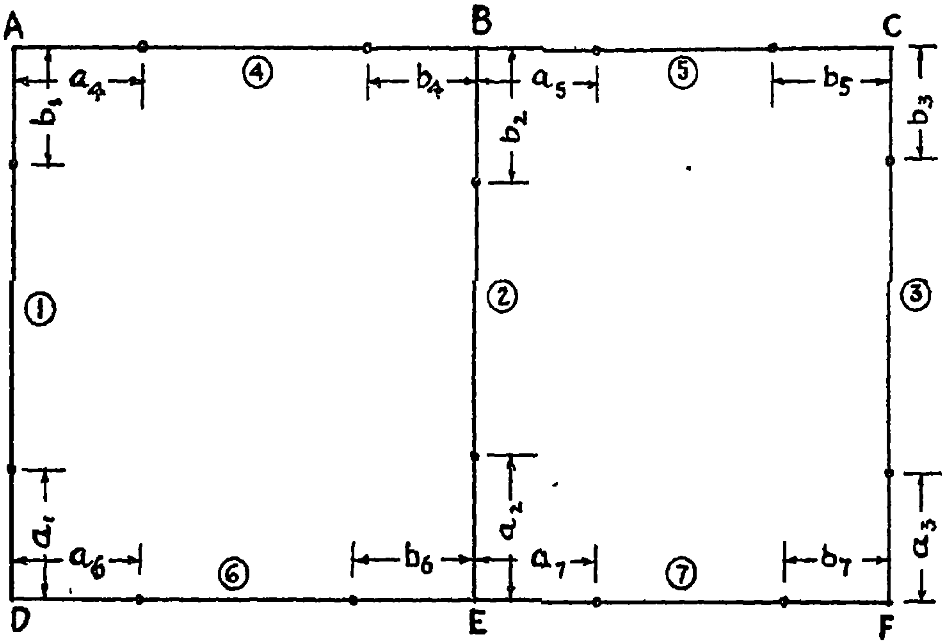


Fig. 1

1, 2, 3, 4 .. etc. are the members of the frame considered

A, B, C, D..etc. are the various nodes or joints

l_1, l_2, l_3 ..etc. are the respective lengths of members *1,2,3*..etc.,

J_1, J_2, J_3..etc. are the respective Moments of Inertia of members *1, 2, 3*.. etc. about their neutral axes.

β is the angle which a member makes at B with AB, when subjected to a unit moment ($M = 1$) applied at A, taking the member freely supported at both ends A & B.

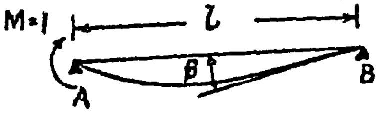


FIG. 2

When the moment of inertia of the member is constant throughout, we have as follows :—$E\beta = \frac{l}{6J}$, where l = length of member, J = Moment of inertia about neutral axis, E = Elastic modulus. $\beta_1, \beta_2, \beta_3$..etc. are for respective members *1, 2, 3*..etc.

τ_1^A is the angle, which a member makes at A with AB, when subjected to a unit moment ($M_1^A = 1$) applied at A, taking the member freely supported at A and fixed at B.

When the moment of inertia of the member is constant throughout we have as follows :—

$$\tau_1^A = \left(3 - \frac{l_1}{l_1 - b_1}\right),$$

where l_1 = length of member and b_1 = distance from B of the adjacent fixed point.

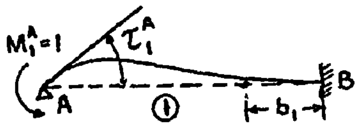


FIG. 5.

$\tau^A_{1\text{-}2\text{-}3\text{-}4\ldots\ldots n}$ is the angle of rotation of a joint A, consisting of members 1, 2, 3, 4...n, when a unit moment ($M_1^A = 1$) is applied to the joint, and we have as follows :—

$$\tau^A_{1\text{-}2\text{-}3\text{-}4\ldots\ldots n} = \frac{1}{\frac{1}{\tau_1^A} + \frac{1}{\tau_2^A} + \frac{1}{\tau_3^A} + \ldots + \frac{1}{\tau_n^A}}.$$

ε_1^a is the angle of rotation of support A (member 1), when a unit moment ($M_1^A = 1$) is applied to this support. This is required in calculating the fixed point distance 'a'.
Similarly ε_1^b is for support B.

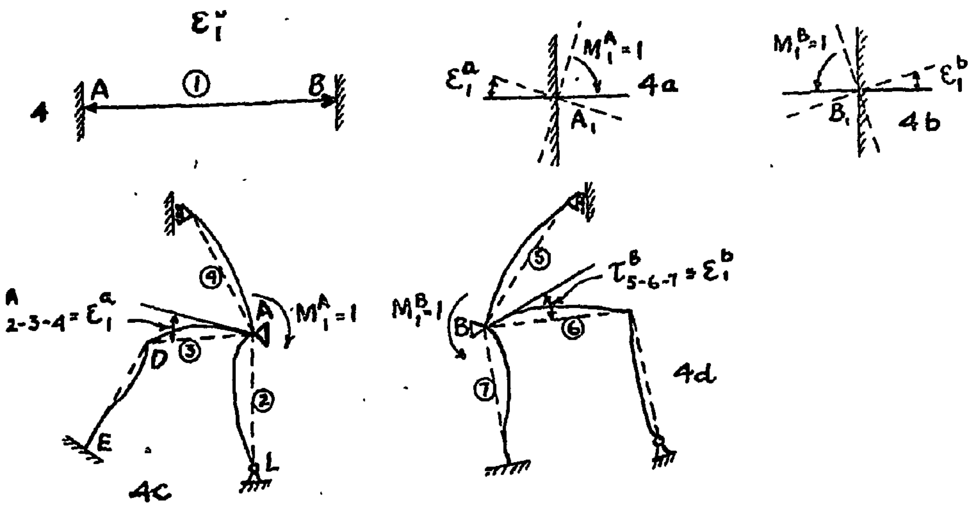


Fig. 4—4 d

In figure 4C, at Node A, the support for member 1 consists of a joint, of members 2, 3, 4..

ε_1^a is, therefore, the angle of rotation of a joint consisting of members 2,3,4. Hence

$$\varepsilon_1^a = \tau_{2\text{-}3\text{-}4}^A$$

Fixed points 'a' and 'b'

'a', for any member, denotes the distance between the left or bottom joint and the adjacent fixed point of the member considered. a_1, a_2, a_3 etc. are for the respective members 1,2,3 etc.

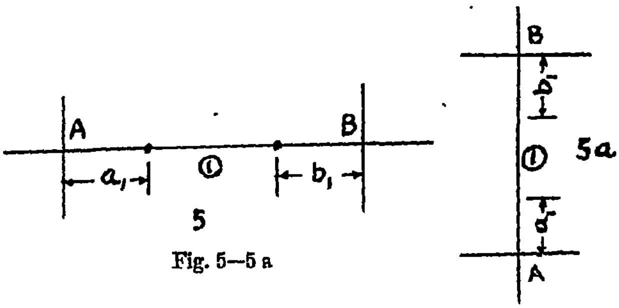


Fig. 5—5 a

'b', for any member, denotes the distance between the right or top joint and the adjacent fixed point of the member considered. b_1, b_2, b_3 etc. ......are for the respective members 1,2,3 etc.

When the moment of inertia of a member is constant throughout, we have as follows:—

$$a = \frac{l}{3 + \frac{\varepsilon^a}{\beta}}$$ where l is the length of the member considered, ε^a and β denote angles as explained before.

$$b = \frac{l}{3 + \frac{\varepsilon^b}{\beta}}$$

Transference Factor 'μ'

Moment M_1^A (fig. 4c) produces at A, moments M_2^A, M_3^A and M_4^A in the respective members 2, 3, 4, the directions being shown by arrows in fig. 6. For equilibrium of joint, we have

$$M_1^A = M_2^A + M_3^A + M_4^A$$

and also, we have

$$M_2^A = M_1^A \cdot \frac{\tau^A_{2\text{-}3\text{-}4}}{\tau^A_2}$$

$$M_3^A = M_1^A \cdot \frac{\tau^A_{2\text{-}3\text{-}4}}{\tau^A_3}$$

$$M_4^A = M_1^A \cdot \frac{\tau^A_{2\text{-}3\text{-}4}}{\tau^A_4}$$

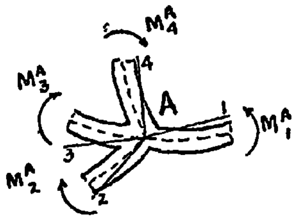


Fig. 6

Moments M_2^A, M_3^A, M_4^A are each less than M_1^A,

Factor $\frac{M_2^A}{M_1^A}$ is called the transference factor, from member 1 to 2 and is denoted by μ^A_{1-2}.

So that we have,

$$\mu^A_{1\text{-}2} = \frac{\tau^A_{2\text{-}3\text{-}4}}{\tau^A_2}$$

$$\mu^A_{1\text{-}3} = \frac{\tau^A_{2\text{-}3\text{-}4}}{\tau^A_3}$$

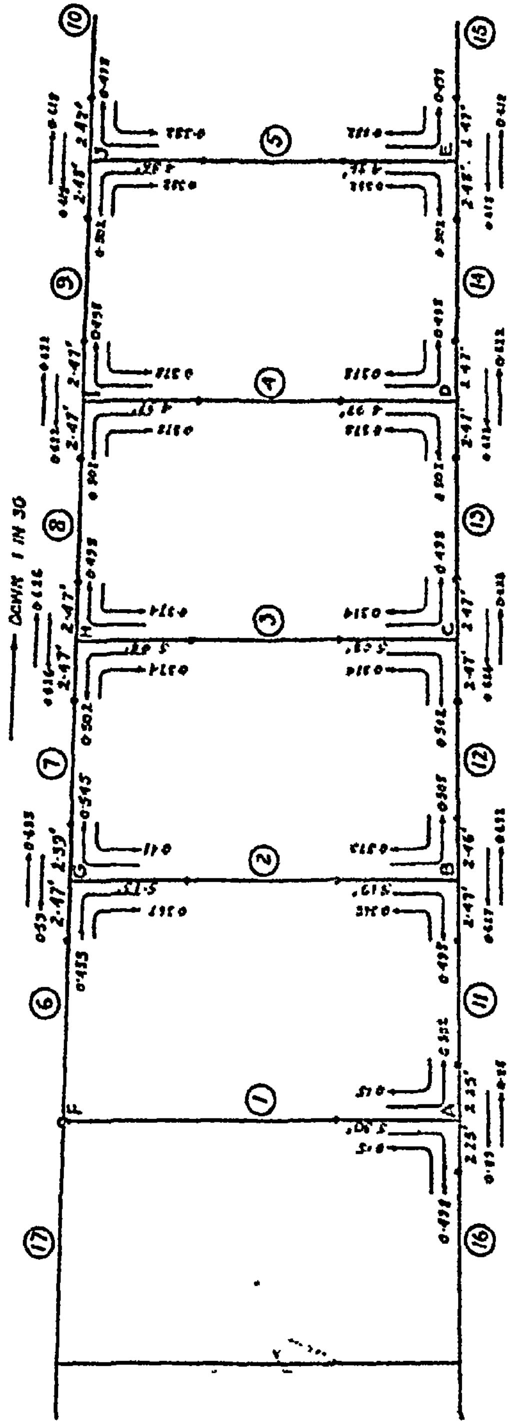
$$\mu^A_{1\text{-}4} = \frac{\tau^A_{2\text{-}3\text{-}4}}{\tau^A_4}$$

All calculations are based on the following assumptions:—

(1) All joints of the frame are rigid, hence there is no relative change of angle between the members themselves.

(2) Movement of joints are possible due to rotation only and no movement due to translation.

For further references, please refer " Methode der Festpunkte " by Ernst Suter.



$l_1 = 18{\cdot}55'$, $l_2 = 15{\cdot}00'$, $l_3 = 17{\cdot}67'$, $l_4 = 17{\cdot}33'$, $l_5 = 17{\cdot}00$, $l_6 = l_7 = \ldots\ldots = l_{15} = l_{16} = 10{\cdot}00'$
MOMENT OF INERTIA J = CONSTANT FOR ALL MEMBERS

CALCULATION OF STIFFNESS FACTORS

$$E\beta_1 = \frac{l_1}{6J_1} = \frac{18{\cdot}33}{6J} = \frac{3{\cdot}06}{J}$$

$$E\beta_2 = \frac{l_2}{6J_2} = \frac{18{\cdot}00}{6J} = \frac{3{\cdot}00}{J}$$

$$E\beta_3 = \frac{17{\cdot}67}{6J} = \frac{2{\cdot}95}{J}$$

$$E\beta_4 = \frac{17{\cdot}33}{6J} = \frac{2{\cdot}89}{J}$$

$$E\beta_5 = \frac{17{\cdot}00}{6J} = \frac{2{\cdot}83}{J}$$

$$E\beta_6 \text{ to } E\beta_{18} = \frac{10{\cdot}00}{6J} = \frac{1{\cdot}67}{J}$$

CALCULATION OF FIXED POINTS

Since there is an expansion joint at F, the members are free at this point.

$\therefore \quad a_6 = 0$ and $b_1 = 0$

$$\tau_6^G = \beta_6 \left(3 - \frac{l_6}{l_6 - a_6}\right)$$

$$= \frac{1{\cdot}67}{EJ}\left(3 - \frac{10}{10-0}\right)$$

$$= \frac{1{\cdot}67}{EJ} \times 2 = \frac{3{\cdot}34}{EJ}$$

Before we can proceed further we have to assume values for some of the fixed points. These assumed values will finally be calculated accurately and altered where necessary.

Assume, $b_2 = 5{\cdot}25$ feet.

$b_3 = 5{\cdot}17$ feet.

$b_4 = 5{\cdot}07$ feet.

$b_5 = 4{\cdot}98$ feet.

$a_{11} = 2{\cdot}40$ feet.

$$\tau_2^B = \beta_2\left(3 - \frac{l_2}{l_2 - b_2}\right)$$

$$= \frac{3{\cdot}00}{EJ}\left(3 - \frac{18{\cdot}00}{18{\cdot}00 - 5{\cdot}25}\right)$$

$$= \frac{3{\cdot}00}{EJ} \times 1{\cdot}59 = \frac{4{\cdot}77}{EJ}$$

$$\tau_{11}^B = \beta_{11}\left(3 - \frac{l_{11}}{l_{11} - a_{11}}\right)$$

$$= \frac{1{\cdot}67}{EJ}\left(3 - \frac{10}{10 - 2{\cdot}40}\right)$$

$$=\frac{1\cdot 67}{EJ}\times 1\cdot 68=\frac{2\cdot 81}{EJ}.$$

$$\tau^B_{2\text{-}11}=\frac{\tau^B_2\times\tau^B_{11}}{\tau^B_2+\tau^B_{11}}$$

$$=\frac{4\cdot 77\times 2\cdot 81}{EJ(4\cdot 77+2\cdot 81)}=\frac{13\cdot 40}{7\cdot 58EJ}=\frac{1\cdot 77}{EJ}=\varepsilon^a_{12}$$

$$a_{12}=\frac{l_{12}}{3+\frac{\varepsilon^a_{12}}{\beta_{12}}}$$

$$=\frac{10}{3+\frac{1\cdot 77}{1\cdot 67}}=\frac{10}{4\cdot 06}=2\cdot 46 \text{ feet.}$$

$$\tau^c_{12}=\beta_{12}\left(3-\frac{l_{12}}{l_{12}-a_{12}}\right)$$

$$=\frac{1\cdot 67}{EJ}\left(3-\frac{10}{10-2\cdot 46}\right)$$

$$=\frac{1\cdot 67}{EJ}\times 1\cdot 67=\frac{2\cdot 79}{EJ}$$

$$\tau^c_3=\beta_3\left(3-\frac{l_3}{l_3-b_3}\right)$$

$$=\frac{2\cdot 95}{EJ}\left(3-\frac{17\cdot 67}{17\cdot 67-5\cdot 17}\right)$$

$$=\frac{2\cdot 95}{EJ}\times 1\cdot 59=\frac{4\cdot 69}{EJ}$$

$$\tau^c_{3\text{-}12}=\frac{\tau^c_3\times\tau^c_{12}}{\tau^c_3+\tau^c_{12}}$$

$$=\frac{4\cdot 69\times 2\cdot 79}{EJ(4\cdot 69+2\cdot 79)}=\frac{13\cdot 09}{7\cdot 48EJ}=\frac{1\cdot 75}{EJ}=\varepsilon^a_{13}$$

$$a_{13}=\frac{l_{13}}{3+\frac{\varepsilon^a_{13}}{\beta_{13}}}$$

$$=\frac{10}{3+\frac{1\cdot 75}{1\cdot 67}}=\frac{10}{4\cdot 05}=2\cdot 47 \text{ feet.}$$

$$\tau^D_4=\beta_4\left(3-\frac{l_4}{l_4-b_4}\right)$$

$$=\frac{2\cdot 89}{EJ}\left(3-\frac{17\cdot 33}{17\cdot 33-5\cdot 07}\right)$$

$$=\frac{2\cdot 89}{EJ}\times 1\cdot 59=\frac{4\cdot 60}{EJ}$$

$$\tau^{D}_{13} = \beta_{13}\left(3 - \frac{l_{13}}{l_{13} - a_{13}}\right)$$

$$= \frac{1·67}{EJ}\left(3 - \frac{10}{10 - 2·47}\right)$$

$$= \frac{1·67}{EJ} \times 1·67 = \frac{2·79}{EJ}$$

$$\tau^{D}_{4\text{-}13} = \frac{\tau^{D}_{4} \times \tau^{D}_{13}}{\tau^{D}_{4} + \tau^{D}_{13}}$$

$$= \frac{4·60 \times 2·79}{EJ(4·60 + 2·79)} = \frac{12·83}{7·39\,EJ} = \frac{1·74}{EJ} = \varepsilon^{a}_{14}$$

$$a_{14} = \frac{l_{14}}{3 + \dfrac{\varepsilon^{a}_{14}}{\beta_{14}}}$$

$$= \frac{10}{3 + \dfrac{1·74}{1·67}} = \frac{10}{4·04} = 2·47 \text{ feet.}$$

The values of a_{15}.....................will now be practically the same as $a_{14} = 2·47$ feet.

As the frame is more or less reversible in character excepting member 6, for other top horizontal members we can assume the fixed points to be the same as those of the corresponding horizontal members at the bottom.

From symmetry, we can also assume

$$b_{15} = a_{15} = 2·47 \text{ feet.}$$

$$\tau^{E}_{15} = \beta_{15}\left(3 - \frac{l_{15}}{l_{15} - b_{15}}\right)$$

$$= \frac{1·67}{EJ}\left(3 - \frac{10}{10 - 2·47}\right)$$

$$= \frac{1·67}{EJ} \times 1·67 = \frac{2·79}{EJ}$$

$$\tau^{E}_{14} = \beta_{14}\left(3 - \frac{l_{14}}{l_{14} - a_{14}}\right)$$

$$= \frac{1·67}{EJ}\left(3 - \frac{10}{10 - 2·47}\right)$$

$$= \frac{1·67}{EJ} \times 1·67 = \frac{2·79}{EJ}$$

$$\tau^{E}_{14\text{-}15} = \frac{\tau^{E}_{14} \times \tau^{E}_{15}}{\tau^{E}_{14} + \tau^{E}_{15}}$$

$$=\frac{2{\cdot}79\times2{\cdot}79}{EJ(2{\cdot}79+2{\cdot}79)}=\frac{7{\cdot}78}{5{\cdot}58\,EJ}=\frac{1{\cdot}40}{EJ}=\varepsilon_5^a$$

$$a_5=\frac{l_5}{3+\dfrac{\varepsilon_5^a}{\beta_5}}$$

$$=\frac{17{\cdot}00}{3+\dfrac{1{\cdot}40}{2{\cdot}83}}=\frac{17{\cdot}00}{3{\cdot}49}=4{\cdot}86 \text{ feet.}$$

$$\tau_5^E=\beta_5\left(3-\frac{l_5}{l_5-b_5}\right)$$

$$=\frac{2{\cdot}83}{EJ}\left(3-\frac{17{\cdot}00}{17{\cdot}00-4{\cdot}98}\right)$$

$$=\frac{2{\cdot}83}{EJ}\times1{\cdot}59=\frac{4{\cdot}50}{EJ}$$

$$\tau_{5\text{-}15}^E=\frac{\tau_5^E\times\tau_{15}^E}{\tau_5^E+\tau_{15}^E}$$

$$=\frac{4{\cdot}50\times2{\cdot}79}{EJ(4{\cdot}50+2{\cdot}79)}=\frac{12{\cdot}55}{7{\cdot}29\,EJ}=\frac{1{\cdot}72}{EJ}=\varepsilon_{14}^b=\tau_{5\text{-}14}^E$$

$$b_{14}=\frac{l_{14}}{3+\dfrac{\varepsilon_{14}^b}{\beta_{14}}}$$

$$=\frac{10}{3+\dfrac{1{\cdot}72}{1{\cdot}67}}=\frac{10}{4{\cdot}03}=2{\cdot}48 \text{ feet.}$$

$$\tau_{14}^D=\beta_{14}\left(3-\frac{l_{14}}{l_{14}-b_{14}}\right)$$

$$=\frac{1{\cdot}67}{EJ}\left(3-\frac{10}{10-2{\cdot}48}\right)$$

$$=\frac{1{\cdot}67}{EJ}\times1{\cdot}67=\frac{2{\cdot}79}{EJ}$$

$$\tau_{13}^D=\beta_{13}\left(3-\frac{l_{13}}{l_{13}-a_{13}}\right)$$

$$=\frac{1{\cdot}67}{EJ}\left(3-\frac{10}{10-2{\cdot}47}\right).$$

$$=\frac{1{\cdot}67}{EJ}\times1{\cdot}67=\frac{2{\cdot}79}{EJ}$$

$$\tau_{13\text{-}14}^D=\frac{\tau_{13}^D\times\tau_{14}^D}{\tau_{13}^D+\tau_{14}^D}$$

$$=\frac{2{\cdot}79\times2{\cdot}79}{EJ(2{\cdot}79+2{\cdot}79)}=\frac{7{\cdot}78}{5{\cdot}58EJ}=\frac{1{\cdot}40}{EJ}=\varepsilon_4^a$$

$$a_4 = \frac{l_4}{3 + \dfrac{\varepsilon_4^a}{\beta_4}}$$

$$= \frac{17{\cdot}33}{3 + \dfrac{1{\cdot}40}{2{\cdot}89}} = \frac{17{\cdot}33}{3{\cdot}48} = 4{\cdot}97 \text{ feet.}$$

$$\tau_4^D = \beta_4\left(3 - \frac{l_4}{l_4 - b_4}\right)$$

$$= \frac{2{\cdot}89}{EJ}\left(3 - \frac{17{\cdot}33}{17{\cdot}33 - 5{\cdot}07}\right)$$

$$= \frac{2{\cdot}89}{EJ} \times 1{\cdot}59 = \frac{4{\cdot}60}{EJ}$$

$$\tau_{4\text{-}14}^D = \frac{\tau_4^D \times \tau_{14}^D}{\tau_4^D + \tau_{14}^D}$$

$$= \frac{4{\cdot}60 \times 2{\cdot}79}{EJ(4{\cdot}60 + 2{\cdot}79)} = \frac{12{\cdot}84}{7{\cdot}39EJ} = \frac{1{\cdot}74}{EJ} = \varepsilon_{13}^b$$

$$b_{13} = \frac{l_{13}}{3 + \dfrac{\varepsilon_{13}^B}{\beta_{13}}}$$

$$= \frac{10}{3 + \dfrac{1{\cdot}74}{1{\cdot}67}} = \frac{10}{4{\cdot}04} = 2{\cdot}47 \text{ feet.}$$

$$\tau_{13}^c = \beta_{13}\left(3 - \frac{l_{13}}{l_{13} - b_{13}}\right)$$

$$= \frac{1{\cdot}67}{EJ}\left(3 - \frac{10}{10 - 2{\cdot}47}\right)$$

$$= \frac{1{\cdot}67}{EJ} \times 1{\cdot}67 = \frac{2{\cdot}79}{EJ}$$

$$\tau_{12}^c = \beta_{12}\left(3 - \frac{l_{12}}{l_{12} - a_{12}}\right)$$

$$= \frac{1{\cdot}67}{EJ}\left(3 - \frac{10}{10 - 2{\cdot}46}\right)$$

$$= \frac{1{\cdot}67}{EJ} \times 1{\cdot}67 = \frac{2{\cdot}79}{EJ}$$

$$\tau_{12\text{-}13}^c = \frac{\tau_{12}^c \times \tau_{13}^c}{\tau_{12}^c + \tau_{13}^c}$$

$$= \frac{2{\cdot}79 \times 2{\cdot}79}{EJ(2{\cdot}79 + 2{\cdot}79)} = \frac{7{\cdot}78}{5{\cdot}58EJ} = \frac{1{\cdot}40}{EJ} = \varepsilon_3^a$$

$$a_3 = \frac{l_3}{3 + \dfrac{\varepsilon_3^a}{\beta_3}}$$

$$=\frac{17{\cdot}67}{3+\frac{1{\cdot}40}{2{\cdot}95}}=\frac{17{\cdot}67}{3{\cdot}47}=5{\cdot}08 \text{ feet.}$$

$$\tau_3^c=\beta_3\left(3-\frac{l_3}{l_3-b_3}\right)$$

$$=\frac{2{\cdot}95}{EJ}\left(3-\frac{17{\cdot}67}{17{\cdot}67-5{\cdot}17}\right)$$

$$=\frac{2{\cdot}95}{EJ}\times 1{\cdot}59=\frac{4{\cdot}68}{EJ}$$

$$\tau_{3\text{-}13}^c=\frac{\tau_3^c\times\tau_{13}^c}{\tau_3^c+\tau_{13}^c}$$

$$=\frac{4{\cdot}68\times 2{\cdot}79}{EJ\,(4{\cdot}68+2{\cdot}79)}=\frac{13{\cdot}06}{7{\cdot}47\,EJ}=\frac{1{\cdot}75}{EJ}=\varepsilon_{12}^b$$

$$b_{12}=\frac{l_{12}}{3+\frac{\varepsilon_{12}^b}{\beta_{12}}}$$

$$=\frac{10}{3+\frac{1{\cdot}75}{1{\cdot}67}}=\frac{10}{4{\cdot}05}=2{\cdot}47 \text{ feet.}$$

$$\tau_{12}^B=\beta_{12}\left(3-\frac{l_{12}}{l_{12}-b_{12}}\right)$$

$$=\frac{1{\cdot}67}{EJ}\left(3-\frac{10}{10-2{\cdot}47}\right)$$

$$=\frac{1{\cdot}67}{EJ}\times 1{\cdot}67=\frac{2{\cdot}79}{EJ}$$

$$\tau_{11}^B=\beta_{11}\left(3-\frac{l_{11}}{l_{11}-a_{11}}\right)$$

$$=\frac{1{\cdot}67}{EJ}\left(3-\frac{10}{10-2{\cdot}40}\right)$$

$$=\frac{1{\cdot}67}{EJ}\times 1{\cdot}68=\frac{2{\cdot}81}{EJ}$$

$$\tau_{11\text{-}12}^B=\frac{\tau_{11}^B\times\tau_{12}^B}{\tau_{11}^B+\tau_{12}^B}$$

$$=\frac{2{\cdot}81\times 2{\cdot}79}{(2{\cdot}81+2{\cdot}79)\,EJ}=\frac{7{\cdot}84}{5{\cdot}60\,EJ}=\frac{1{\cdot}40}{EJ}=\varepsilon_2^a$$

$$a_2=\frac{l_2}{3+\frac{\varepsilon_2^a}{\beta_2}}$$

$$=\frac{18{\cdot}00}{3+\frac{1{\cdot}40}{3{\cdot}00}}=\frac{18{\cdot}00}{3{\cdot}47}=5{\cdot}19 \text{ feet.}$$

$$\tau_2^B = \beta_2\left(3 - \frac{l_2}{l_2 - b_2}\right)$$

$$= \frac{3{\cdot}00}{EJ}\left(3 - \frac{18{\cdot}00}{18{\cdot}00 - 5{\cdot}25}\right)$$

$$= \frac{3{\cdot}00}{EJ} \times 1{\cdot}59 = \frac{4{\cdot}77}{EJ}$$

$$\tau_{2\text{-}12}^B = \frac{\tau_2^B \times \tau_{12}^B}{\tau_2^B + \tau_{12}^B}$$

$$= \frac{4{\cdot}77 \times 2{\cdot}79}{(4{\cdot}77 + 2{\cdot}79)\ EJ} = \frac{13{\cdot}31}{7{\cdot}56\ EJ} = \frac{1{\cdot}76}{EJ} = \varepsilon_{11}^b$$

$$b_{11} = \frac{l_{11}}{3 + \frac{\varepsilon_{11}^b}{\beta_{11}}}$$

$$= \frac{10}{3 + \frac{1{\cdot}76}{1{\cdot}67}} = \frac{10}{4{\cdot}05} = 2{\cdot}47 \text{ feet.}$$

$$\tau_{11}^A = \beta_{11}\left(3 - \frac{l_{11}}{l_{11} - b_{11}}\right)$$

$$= \frac{1{\cdot}67}{EJ}\left(3 - \frac{10}{10 - 2{\cdot}47}\right)$$

$$= \frac{1{\cdot}67}{EJ} \times 1{\cdot}67 = \frac{2{\cdot}79}{EJ}$$

$$\tau_{16}^A \sim \tau_{11}^A = \frac{2{\cdot}79}{EJ}$$

$$\tau_{11\text{-}16}^A = \frac{\tau_{11}^A \times \tau_{16}^A}{\tau_{11}^A + \tau_{16}^A}$$

$$= \frac{2{\cdot}79 \times 2{\cdot}79}{(2{\cdot}79 + 2{\cdot}79)EJ} = \frac{7{\cdot}78}{5{\cdot}58EJ} = \frac{1{\cdot}40}{EJ} = \varepsilon_1^a$$

$$a_1 = \frac{l_1}{3 + \frac{\varepsilon_1^a}{\beta_1}}$$

$$= \frac{18{\cdot}33}{3 + \frac{1{\cdot}40}{3{\cdot}06}} = \frac{18{\cdot}33}{3{\cdot}46} = 5{\cdot}30 \text{ feet.}$$

$$\tau_1^A = \beta_1\left(3 - \frac{l_1}{l_1 - b_1}\right)$$

$$= \frac{3{\cdot}06}{EJ}\left(3 - \frac{18{\cdot}33}{18{\cdot}33 - 0}\right)$$

$$= \frac{3{\cdot}06}{EJ} \times 2 = \frac{6{\cdot}12}{EJ}$$

$$\tau^{A}_{1\text{-}16} = \frac{\tau^{A}_{1} \times \tau^{A}_{16}}{\tau^{A}_{1} + \tau^{A}_{16}}$$

$$= \frac{6{\cdot}12 \times 2{\cdot}79}{(6{\cdot}12 + 2{\cdot}79)EJ} = \frac{17{\cdot}07}{8{\cdot}91EJ} = \frac{1{\cdot}92}{EJ} = \varepsilon^{a}_{11}$$

$$a_{11} = \frac{l_{11}}{3 + \dfrac{\varepsilon^{a}_{11}}{\beta_{11}}}$$

$$= \frac{10}{3 + \dfrac{1{\cdot}92}{1{\cdot}67}} = \frac{10}{4{\cdot}15} = 2{\cdot}41 \text{ feet.}$$

$$\tau^{G}_{2} = \beta_2\left(3 - \frac{l_2}{l_2 - a_2}\right)$$

$$= \frac{3{\cdot}00}{EJ}\left(3 - \frac{18{\cdot}00}{18{\cdot}00 - 5{\cdot}19}\right)$$

$$= \frac{3{\cdot}00}{EJ} \times 1{\cdot}60 = \frac{4{\cdot}80}{EJ}$$

$$\tau^{G}_{7} = \beta_7\left(3 - \frac{l_7}{l_7 - b_7}\right)$$

$$= \frac{1{\cdot}67}{EJ}\left(3 - \frac{10}{10 - 2{\cdot}47}\right)$$

$$= \frac{1{\cdot}67}{EJ} \times 1{\cdot}67 = \frac{2{\cdot}79}{EJ}$$

$$\tau^{G}_{2\text{-}7} = \frac{\tau^{G}_{2} \times \tau^{G}_{7}}{\tau^{G}_{2} + \tau^{G}_{7}}$$

$$= \frac{4{\cdot}80 \times 2{\cdot}79}{(4{\cdot}80 + 2{\cdot}79)EJ} = \frac{13{\cdot}39}{7{\cdot}59EJ} = \frac{1{\cdot}76}{EJ} = \varepsilon^{b}_{6}$$

$$b_6 = \frac{l_6}{3 + \dfrac{\varepsilon^{b}_{6}}{\beta_6}}$$

$$= \frac{10}{3 + \dfrac{1{\cdot}76}{1{\cdot}67}} = \frac{10}{4{\cdot}05} = 2{\cdot}47 \text{ feet.}$$

$$\tau^{G}_{6} = \beta_6\left(3 - \frac{l_6}{l_6 - a_6}\right)$$

$$= \frac{1{\cdot}67}{EJ}\left(3 - \frac{10}{10 - 0}\right)$$

$$= \frac{1{\cdot}67}{EJ} \times 2 = \frac{3{\cdot}34}{EJ}$$

$$\tau^{G}_{6\text{-}7} = \frac{\tau^{G}_{6} \times \tau^{G}_{7}}{\tau^{G}_{6} + \tau^{G}_{7}}$$

$$= \frac{3{\cdot}34 \times 2{\cdot}79}{(3{\cdot}34+2{\cdot}79)EJ} = \frac{9{\cdot}32}{6{\cdot}13EJ} = \frac{1{\cdot}52}{EJ} = \varepsilon_2^b$$

$$b_2 = \frac{l_2}{3+\dfrac{\varepsilon_2^b}{\beta_2}}$$

$$= \frac{18{\cdot}00}{3+\dfrac{1{\cdot}52}{3{\cdot}00}} = \frac{18{\cdot}00}{3{\cdot}51} = 5{\cdot}13 \text{ feet.}$$

If there is any live load on member 7, the tendency of member 6 will be to lift at the point *F*. The member 6 will, in that case, act as a cantilever thus offering no restraint at the node *G*. But it is expected that the dead load of member 6 will be sufficient to counteract this upward tendency and hence in spite of the absence of any mechanical hinge at *F*, the member 6 will act as a span as if hinged at *F*, and will thus offer some restraint. The fixed point a_7 is calculated on this assumption. If, later on, it is found that there is some nett upward reaction at *F*, the restraint offered by member 6 will have to be neglected and the value of a_7 revised accordingly.

$$\tau_{2\text{-}6}^G = \frac{\tau_2^G \times \tau_6^G}{\tau_2^G + \tau_6^G}$$

$$= \frac{4{\cdot}80 \times 3{\cdot}34}{(4{\cdot}80+3{\cdot}34)\,EJ} = \frac{16{\cdot}05}{8{\cdot}14EJ} = \frac{1{\cdot}97}{EJ} = \varepsilon_7^a$$

$$a_7 = \frac{l_7}{3+\dfrac{\varepsilon_7^a}{\beta_7}}$$

$$= \frac{10}{3+\dfrac{1{\cdot}97}{1{\cdot}67}} = \frac{10}{4{\cdot}18} = 2{\cdot}39 \text{ feet.}$$

Previously the value of a_{11} has been calculated on the assumption that the point *F* of number 1 is free to rotate but fixed in position. Except for the slight frictional resistance at the joint, the point *F* of this member is also free to move laterally, in that case this member will offer no restraint at the node *A* and we shall now calculate the value of a_{11} on this assumption.

$$\tau_{16}^A = \frac{2{\cdot}79}{EJ} = \varepsilon_{11}^a$$

$$a_{11} = \frac{l_{11}}{3+\dfrac{\varepsilon_{11}^a}{\beta_{11}}}$$

$$= \frac{10}{3+\dfrac{2{\cdot}79}{1{\cdot}67}} = \frac{10}{4{\cdot}67} = 2{\cdot}14 \text{ feet.}$$

The actual value of a_{11} will be something in between the value of 2·41 feet calculated before and this value of 2·14 feet; the exact magnitude depending on the amount of frictional resistance at F. We shall assume the value of

$$a_{11} = 2{\cdot}25 \text{ feet.}$$

To begin with, we assumed a value of 2·40 feet for a_{11}, and thence calculated the value of a_{12}. This slight difference in value of a_{11} may also alter the value of a_{12}, the effect on the values of other fixed points being negligible. We shall now recalculate the value of a_{12}.

$$\tau^B_{11} = \beta_{11}\left(3 - \frac{l_{11}}{l_{11} - a_{11}}\right)$$

$$= \frac{1{\cdot}67}{EJ}\left(3 - \frac{10}{10 - 2{\cdot}25}\right)$$

$$= \frac{1{\cdot}67}{EJ} \times 1{\cdot}71 = \frac{2{\cdot}85}{EJ}$$

$$\tau^B_2 = \beta_2\left(3 - \frac{l_2}{l_2 - b_2}\right)$$

$$= \frac{3{\cdot}00}{EJ}\left(3 - \frac{18{\cdot}00}{18{\cdot}00 - 5{\cdot}13}\right)$$

$$= \frac{3{\cdot}00}{EJ} \times 1{\cdot}60 = \frac{4{\cdot}80}{EJ}$$

$$\tau^B_{2\text{-}11} = \frac{\tau^B_2 \times \tau^B_{11}}{\tau^B_2 + \tau^B_{11}}$$

$$= \frac{4{\cdot}80 \times 2{\cdot}85}{(4{\cdot}80 + 2{\cdot}85)EJ} = \frac{13{\cdot}68}{7{\cdot}65EJ} = \frac{1{\cdot}79}{EJ} = \varepsilon^a_{12}$$

$$a_{12} = \frac{l_{12}}{3 + \dfrac{\varepsilon^a_{12}}{\beta_{12}}}$$

$$= \frac{10}{3 + \dfrac{1{\cdot}79}{1{\cdot}67}} = \frac{10}{4{\cdot}07} = 2{\cdot}46 \text{ feet.}$$

$$\tau^B_{11\text{-}12} = \frac{2{\cdot}85 \times 2{\cdot}79}{(2{\cdot}85 + 2{\cdot}79)EJ} = \frac{7{\cdot}95}{5{\cdot}64EJ} = \frac{1{\cdot}41}{EJ}$$

CALCULATION OF TRANSFERENCE FACTORS

Node—'A' :—

$$\mu^A_{1 \text{ to } 11} = \frac{\tau^A_{11\text{-}16}}{\tau^A_{11}} = \frac{1{\cdot}40}{2{\cdot}79} = 0{\cdot}502$$

$$\mu^A_{1\text{-}16} = 1 - 0{\cdot}502 \qquad = 0{\cdot}498$$

$$\mu^{A}_{11\text{-}16}=\frac{\tau^{A}_{1\text{-}16}}{\tau^{A}_{16}}=\frac{1{\cdot}92}{2{\cdot}79}=0{\cdot}69$$

If we neglect the restraint due to member $1, \mu^{A}_{11\text{-}16}=1{\cdot}00$; and hence taking an intermediate value, we shall assume

$$\mu^{A}_{11\text{-}16}=0{\cdot}85=\mu^{A}_{16\text{-}11}, \text{ from symmetry.}$$

$$\mu^{A}_{11\text{-}1}=1-0{\cdot}85=0{\cdot}15=\mu^{A}_{16\text{-}1}$$

Node—'B' :—

$$\mu^{B}_{2\text{-}11}=\frac{\tau^{B}_{11\text{-}12}}{\tau^{B}_{11}}=\frac{1{\cdot}41}{2{\cdot}85}=0{\cdot}495$$

$$\mu^{B}_{2\text{-}12}=1-0{\cdot}495=0{\cdot}505$$

$$\mu^{B}_{11\text{-}2}=\frac{\tau^{B}_{2\text{-}12}}{\tau^{B}_{2}}=\frac{1{\cdot}76}{4{\cdot}80}=0{\cdot}368$$

$$\mu^{B}_{11\text{-}12}=1-0{\cdot}368=0{\cdot}632$$

$$\mu^{B}_{12\text{-}2}=\frac{\tau^{B}_{2\text{-}11}}{\tau^{B}_{2}}=\frac{1{\cdot}79}{4{\cdot}80}=0{\cdot}373$$

$$\mu^{B}_{12\text{-}11}=1-0{\cdot}373=0{\cdot}627$$

Node—'C' :—

$$\mu^{C}_{3\text{-}12}=\frac{\tau^{C}_{12\text{-}13}}{\tau^{C}_{12}}=\frac{1{\cdot}40}{2{\cdot}79}=0{\cdot}502$$

$$\mu^{C}_{3\text{-}13}=1-0{\cdot}502=0{\cdot}498$$

$$\mu^{C}_{12\text{-}3}=\frac{\tau^{C}_{3\text{-}13}}{\tau^{C}_{3}}=\frac{1{\cdot}75}{4{\cdot}68}=0{\cdot}374$$

$$\mu^{C}_{12\text{-}13}=1-0{\cdot}374=0{\cdot}626$$

$$\mu^{C}_{13\text{-}3}=\frac{\tau^{C}_{3\text{-}12}}{\tau^{C}_{3}}=\frac{1{\cdot}75}{4{\cdot}68}=0{\cdot}374$$

$$\mu^{C}_{13\text{-}12}=1-0{\cdot}374=0{\cdot}626$$

Node—'D' :—

$$\mu^{D}_{4\text{-}13}=\frac{\tau^{D}_{13\text{-}14}}{\tau^{D}_{13}}=\frac{1{\cdot}40}{2{\cdot}79}=0{\cdot}502$$

$$\mu^D_{4\text{-}14} = 1 - 0{\cdot}502 = 0{\cdot}498$$

$$\mu^D_{13\text{-}4} = \frac{\tau^D_{4\text{-}14}}{\tau^D_4} = \frac{1{\cdot}74}{4{\cdot}60} = 0{\cdot}378$$

$$\mu^D_{13\text{-}14} = 1 - 0{\cdot}378 = 0{\cdot}622$$

$$\mu^D_{14\text{-}4} = \frac{\tau^D_{4\text{-}13}}{\tau^D_4} = \frac{1{\cdot}74}{4{\cdot}60} = 0{\cdot}378$$

$$\mu^D_{14\text{-}13} = 1 - 0{\cdot}378 = 0{\cdot}622$$

Node—'E' :—

$$\mu^E_{5\text{-}14} = \frac{\tau^E_{14\text{-}15}}{\tau^E_{14}} = \frac{1{\cdot}40}{2{\cdot}79} = 0{\cdot}502$$

$$\mu^E_{5\text{-}15} = 1 - 0{\cdot}502 = 0{\cdot}498$$

$$\mu^E_{14\text{-}5} = \frac{\tau^E_{5\text{-}15}}{\tau^E_5} = \frac{1{\cdot}72}{4{\cdot}50} = 0{\cdot}382$$

$$\mu^E_{14\text{-}15} = 1 - 0{\cdot}382 = 0{\cdot}618$$

$$\mu^E_{15\text{-}5} = \frac{\tau^E_{5\text{-}14}}{\tau^E} = \frac{1{\cdot}72}{4{\cdot}50} = 0{\cdot}382$$

$$\mu^E_{15\text{-}14} = 1 - 0{\cdot}382 = 0{\cdot}618$$

From symmetry, the transference factors at the nodes J, I and H will be similar to those at the nodes E, D and C respectively; the factors at node G will be slightly different to those at node B.

Node—'G' :—

$$\mu^G_{2\text{-}6} = \frac{\tau^G_{6\text{-}7}}{\tau^G_6} = \frac{1{\cdot}52}{3{\cdot}34} = 0{\cdot}455$$

$$\mu^G_{2\text{-}7} = 1 - 0{\cdot}455 = 0{\cdot}545$$

$$\mu^G_{6\text{-}2} = \frac{\tau^G_{2\text{-}7}}{\tau^G_2} = \frac{1{\cdot}76}{4{\cdot}80} = 0{\cdot}367$$

$$\mu^G_{6\text{-}7} = 1 - 0{\cdot}367 = 0{\cdot}633$$

$$\mu^G_{7\text{-}2} = \frac{\tau^G_{2\text{-}6}}{\tau^G_2} = \frac{1{\cdot}97}{4{\cdot}80} = 0{\cdot}41$$

$$\mu^G_{7\text{-}6} = 1 - 0{\cdot}41 = 0{\cdot}59$$

DEAD LOAD MOMENTS.

For convenience in calculation we shall consider a foot-strip of slab and walls.

Weight per square foot of deck slab (with wearing course):—

9" R. C. slab = ·75 × 150	=	113	pounds
2" wearing course = 140/6	=	24	pounds
1/4" layer of asphalt	say =	3	pounds
		140	pounds per square foot.

Free bending moment at the centre of each span $= \frac{Wl^2}{8}$

$$= \frac{140 \times 10 \times 10}{8} = 1750 \text{ foot pounds.}$$

Free reaction at the top of each support

$$= \frac{140 \times 10}{2} = 700 \text{ pounds (due to each span).}$$

Weight of each wall (average height = 17 feet say)

$$= 17 \times 113 = 1920 \text{ pounds.}$$

$\therefore$ total dead load upward reaction on base slab producing moments

$$= 2 \times 700 + 2 \times \frac{1920}{2} = 3320 \text{ pounds.}$$

$\therefore$ free moment at centre of base slab (due to dead load) $= \frac{Wl}{8}$

$$= \frac{3320 \times 10}{8} = 4150 \text{ foot pounds.}$$

The moment diagrams have been drawn graphically (vide Drawing No. 2) and the dead load moments tabulated on page 112. For practical purposes it will be sufficient to find the moments for members constituting the first two openings *i.e.*, for members 1,2,3,6,7, 11 and 12. The reinforcements in members of the first opening may be slightly different but for practical reasons all other members will be made similar to the members of the second opening.

In the following table we shall use the following notations :—

F_6 = point F of member 6, and so on.

F_6G = middle point of member FG or 6, and so on.

$G\frac{1}{7}$ = quarter point of member 7, measured from G, and so on.

DEAD LOAD MOMENTS.

Section.	Dead load moments.	
	In foot pounds.	In foot tons.
A_1	nil	nil
F_1	nil	nil
B_2	+70	+0·03
G_2	−85	−0·04
C_3	nil	nil
H_3	nil	nil
F_6	nil	nil
$F_6^{\frac{1}{4}}$	+900	+0·40
F_6G	+970	+0·43
$G_6^{\frac{1}{4}}$	+155	+0·07
G_6	−1560	−0·70
G_7	−1490	−0·67
$G_7^{\frac{1}{4}}$	−60	−0·03
G_7H	+480	+0·21
$H_7^{\frac{1}{4}}$	+150	+0·07
H_7	−1040	−0·46
A_{11}	−3130	−1·40
$A_{11}^{\frac{1}{4}}$	+216	+0·10
$A_{11}B$	+1393	+0·62
$B_{11}^{\frac{1}{4}}$	+411	+0·18
B_{11}	−2710	−1·21
B_{12}	−2893	−1·29
B_{12}	+313	+0·14
$B_{12}C$	+1360	+0·61
$C_{12}^{\frac{1}{4}}$	+324	+0·14
C_{12}	−2850	−1·27

DEAD LOAD REACTIONS

Reaction at F_1

From member '6' $= 700 = \frac{1560}{10} = 700 - 156 = 544$ pounds.

$\therefore$ total dead load reaction from two spans, one on each side $= 2 \times 544 = 1088$ lbs. $= 0{\cdot}486$ ton.

Reaction at A_1

Weight of wall $= (18{\cdot}33 - 0{\cdot}75) \times 113 = 17{\cdot}58 \times 113$
$= 1987$ pounds.

$\therefore$ total reaction $= 1088 + 1987 = 3075$ lbs. $= 1{\cdot}374$ tons.

Reaction at G_2

From member '6' $= 700 + \frac{1560}{10} = 700 + 156 = 856$ pounds.

From member '7' $= 700 + \frac{(1490 - 1040)}{10} = 700 + 45 = 745$ pounds.

$\therefore$ total reaction at $G_2 = 1601$ lbs. $= 0{\cdot}715$ ton.

Reaction at B_2

Weight of wall $= (18{\cdot}00 - 0{\cdot}75) \times 113 = 17{\cdot}25 \times 113$
$= 1950$ pounds.

$\therefore$ total reaction $= 1601 + 1950 = 3551$ lbs. $= 1{\cdot}585$ tons.

Reaction at H_3

From member '7' $= 700 - 45 = 655$ pounds.
From member '8' $= 700$ pounds approximately.
$\therefore$ total reaction at $H_3 = 1355$ lbs. $= 0{\cdot}605$ ton.

Reaction at C_3

Weight of wall $= (17{\cdot}67 - 0{\cdot}75)\ 113 = 1911$ pounds.
$\therefore$ total reaction $= 1355 + 1911 = 3266$ lbs. $= 1{\cdot}458$ tons.

LIVE LOAD MOMENTS.

The bridge is to be designed to carry per line of traffic, either a 10 ton Steam Roller or a line of 6-ton lorries, whichever produces the greatest stress on the member under design.

In this case, for bending and shear, a 10-ton Steam Roller produces maximum effect. Impact is taken as 50 per cent for such short spans.

The roller is supposed to occupy a space of 25 feet along the length of the bridge; the unoccupied space may be covered with a crowd load of 80 pounds per square foot but as the spans of the bridge are only 10 feet each, the effect of this crowd load will be negligible and hence to simplify calculations we shall consider the roller only.

The details of the roller in its working condition are given below:—

Weight of front wheel (without impact) = 4·30 tons,

Width of front wheel = 4′ – 0″

Weight of each of the two hind wheels (without impact)

= 4·35 tons.

Width of each hind wheel = 1′–6″

Centre to centre of hind wheels = 5′–0″

Wheel base (or distance between two axles) = 10′–8″

Hind wheels—

Weight of each hind wheel with 50 per cent impact

$= 1{\cdot}5 \times 4{\cdot}35 \qquad = 6{\cdot}53$ tons.

Width of distribution $= 2/3\ (L+C)$, where

$L =$ span, and $C =$ tyre width

$= 2/3\ (10 + 1{\cdot}50) = 2/3 \times 11{\cdot}50 = 7{\cdot}67$ feet.

But the maximum possible width of distribution

= distance between centres of hind wheels = 5 feet.

Therefore considering a foot-strip of slab as before,

load due to each hind wheel $= \dfrac{6{\cdot}53}{5} = 1{\cdot}31$ tons, nearly.

Front wheels—

Weight of wheel with 50 per cent impact

$= 1{\cdot}5 \times 4{\cdot}3 \qquad = 6{\cdot}45$ tons.

Width of distribution $= 2/3\ (L+C)$

$= 2/3\ (10+4) = 2/3 \times 14 = 9{\cdot}33$ feet.

$\therefore$ load per strip of slab $= \dfrac{6{\cdot}45}{9{\cdot}33} = 0{\cdot}69$ tons.

We shall neglect the distribution in the longitudinal direction and consider the wheel loads as knife-edge loads.

We shall now place the wheel loads at different positions to give worst effects at the various sections and find out the magnitude of the moments from the graphical constructions for moment diagrams (vide Drawing No. 3).

Section A_1—

(*a*) Maximum positive moment—When one hind wheel is on member '17' about 4 feet from $F = +0{\cdot}12$ foot tons. Corresponding reaction at $A_1 = 6/10 \times 1{\cdot}31 = 0{\cdot}786$ tons.

(*b*) Maximum negative moment—When one hind wheel is on member '6' about 4 feet from F = Maximum positive moment in magnitude $= -0{\cdot}12$ foot tons.

Corresponding reaction at $A_1 = 0{\cdot}786$ ton.

Section F_1—

(*a*) and (*b*)—The member being free at F the moments at this section will be nil.

Section B_2—

(*a*) Maximum positive moment—When one hind wheel is on member '7' about 4 feet from $G = +0{\cdot}21$ foot tons. Corresponding reaction at $B_2 = 0{\cdot}786$ ton.

(*b*) Maximum negative moment—When one hind wheel is on member '6' about 4 feet from $G = -0{\cdot}25$ foot tons. Corresponding reaction at $B_2 = 0{\cdot}786$ ton.

Section G_2—

(*a*) Maximum positive moment—When one hind wheel is on member '6' about 4 feet from $G = +0{\cdot}62$ foot tons. Corresponding reaction at $G_2 = 0{\cdot}786$ ton.

(*b*) Maximum negative moment—When one hind wheel is on member '7' about 4 feet from $G = -0{\cdot}52$ foot tons. Corresponding reaction at $G_2 = 0{\cdot}786$ ton.

Section C_3—

(*a*) Maximum positive moment—When one hind wheel is on member '8' about 4 feet from $H = +0{\cdot}20$ foot tons. Corresponding reaction at $C_3 = 0{\cdot}786$ ton.

(*b*) Maximum negative moment—When one hind wheel is on member '7' about 4 feet from $H = -0{\cdot}20$ foot ton. Corresponding reaction at $C_3 = 0{\cdot}786$ ton.

Section H_3—

(*a*) Maximum positive moment—When one hind wheel is on member '7' about 4 feet from $H = +0{\cdot}50$ foot tons. Corresponding reaction at $H_3 = 0{\cdot}786$ ton.

(*b*) Maximum negative moment—When one hind wheel is on member '8' about 4 feet from $H = -0{\cdot}50$ foot ton. Corresponding reaction at $H_3 = 0{\cdot}786$ ton.

Section F_6—

(*a*) Maximum positive moment .... = nil.
Maximum negative moment .... = nil.

Section $F\frac{1}{6}$—

(*a*) Maximum positive moment—When one hind wheel is at the section considered $= +2{\cdot}22$ foot tons.

(*b*) Maximum negative moment—When one hind wheel is on member '7' about 4 feet from $G = -0{\cdot}20$ foot tons.

Section F_6G—

(*a*) Maximum positive moment—When one hind wheel is at the section considered $= +2{\cdot}48$ foot tons.

(*b*) Maximum negative moment—When one hind wheel is on member '7' about 4 feet from $G = -0{\cdot}40$ foot tons.

Section $G\frac{1}{6}$

(*a*) Maximum positive moment—When one hind wheel is at the section considered $= +1{\cdot}44$ foot tons.

(*b*) Maximum negative moment—When one hind wheel is on member '7' about 4 feet from $G = -0{\cdot}60$ foot tons.

Section G_6

(*a*) Maximum positive moment—When one hind wheel is on member '8' about 4 feet from $H = +0{\cdot}16$ foot tons.

(*b*) Maximum negative moment—When one hind wheel is on member '6' about 4 feet from G and the front wheel is on member '7' $= -1{\cdot}98$ foot tons.

Section G_7—

(*a*) Maximum positive moment—When one hind wheel is on member '8' about 4 feet from $H = +0{\cdot}28$ foot tons.

(*b*) Maximum negative moment—When one hind wheel is on member '7' about 4 feet from G and the front wheel is on member '6' $= -1{\cdot}74$ foot tons.

Section $G\frac{1}{7}$—

(*a*) Maximum positive moment—When one hind wheel is at the section considered $= +1{\cdot}48$ foot tons.

(*b*) Maximum negative moment—When one hind wheel is on member '6' about 4 feet from $G = -0{\cdot}77$ foot tons.

Section G_7H—

(*a*) Maximum positive moment—When one hind wheel is at the section considered $= +2{\cdot}12$ foot tons.

(*b*) Maximum negative moment – When one hind wheel is on member '6' about 4 feet from $G = -0{\cdot}38$ foot tons.

Section $H^{\frac{1}{2}}_{7}$—

(*a*) Maximum positive moment – When one hind wheel is at the section considered $= +1{\cdot}44$ foot tons.

(*b*) Maximum negative moment – When one hind wheel is on member '8' about 4 feet from $H = -0{\cdot}60$ foot tons.

Section H_7—

(*a*) Maximum positive moment – When one hind wheel is on member '6' about 4 feet from $G = +0{\cdot}38$ foot tons.

(*b*) Maximum negative moment – When one hind wheel is on member '7' about 4 feet from *H* and the front wheel is on member '8' $= -1{\cdot}65$ foot tons.

Section A_{11}—

(*a*) Maximum positive moment—When both the front and the hind wheels are nearly on member 7, *i.e.*, when the two wheels are really on members '6' and '8' but the loads can be assumed to be wholly transferred through columns 2 and $3 = +0{\cdot}23$ foot tons.

(*b*) Maximum negative moment – When both the front and the hind wheels are on member '6' $= -1{\cdot}04$ foot tons.

Section $A^{\frac{1}{2}}_{11}$—

(*a*) Maximum positive moment – When both the wheels (front and one hind) are on member '6' $= +0{\cdot}74$ foot tons.

(*b*) Maximum negative moment – When both the wheels are on member '17' $= -0{\cdot}61$ foot tons.

Section $A_{11}B$—

(*a*) Maximum positive moment – When both the wheels are on member '6' $= +1{\cdot}31$ foot tons.

(*b*) Maximum negative moment – When both the wheels are on member '17' $= -0{\cdot}30$ foot tons.

Section $B^{\frac{1}{2}}_{11}$—

(*a*) Maximum positive moment – When both the wheels are on member '6' $= +0{\cdot}61$ foot tons.

(*b*) Maximum negative moment—When both the wheels are on member '7' $= -0{\cdot}51$ foot tons.

Section B_{11}—

(*a*) Maximum positive moment—When both the wheels (front and one hind) are on member '17' $= +0{\cdot}31$ foot tons.

(*b*) Maximum negative moment—When both the wheels are on member '6' = −1·33 foot tons.

Section B_{12}—

(*a*) Maximum positive moment—When both the wheels are on member '8' = +0·26 foot tons.

(*b*) Maximum negative moment—When both the wheels are on member '7' = −1·22 foot tons

Section $B\frac{1}{12}$—

(*a*) Maximum positive moment—When both the wheels are on member '7' = +0·64 foot tons.

(*b*) Maximum negative moment—When both the wheels are on member '6' = −0·56 foot tons.

Section $B_{12}C$—

(*a*) Maximum positive moment—When both the wheels (front and one hind) are on member '7' = + 1·26 foot tons.

(*b*) Maximum negative moment—When both the wheels are on member '6' = −0·27 foot tons.

Section $C\frac{1}{12}$—

(*a*) Maximum positive moment—When both the wheels are on member '7' = +0·62 foot tons.

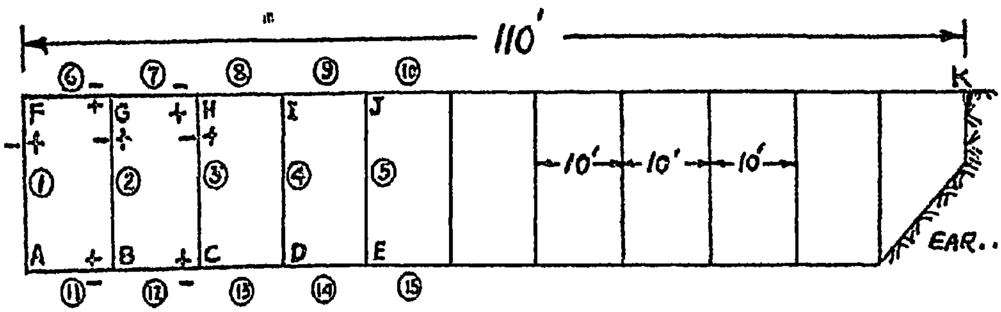
(*b*) Maximum negative moment—When both the wheels are on member '8' = −0·52 foot tons.

Section C_{12}—

(*a*) Maximum positive moment—When both the wheels are on member '6' = + 0·28 foot tons.

(*b*) Maximum negative moment—When both the wheels are on member '7' = − 1·26 foot tons.

TEMPERATURE MOMENTS



We shall have to consider the effects of temperature from the following view points: —

(a) The difference in heights between the different columns being very small, the relative vertical movement can be neglected and hence there will be no moments on this account.

(b) The top horizontal member being exposed to atmosphere will be affected by variations of temperature; whereas the bottom slab being always under water (where the temperature varies very little) will practically be unaffected by external atmospheric variations. Hence there will be relative displacement between these two members. This will produce moments in the columns which, on account of rigidity of joints, will then be transferred on to other members of the structure.

There being earth filling at the back of the abutment; the point K will be practically fixed in position, all movements due to temperature being allowed for at F, where we have a sliding joint.

We shall allow for a variation in temperature of $\pm 30^\circ F$, so that $t = \pm 30^\circ F$

$\alpha =$ coefficient of linear expansion for reinforced concrete

$= {\cdot}000006$ per degree F.

$E =$ Young's modulus for reinforced concrete

$= 128571$ tons per square foot.

We are considering a footstrip of slabs and columns which are 9″ thick.

$\therefore$ moment of inertia about the neutral axis $= J = \dfrac{bd^3}{12}$

$$= \frac{1 \times ({\cdot}75)^3}{12} = 0{\cdot}035 \text{ ft.}^4$$

We shall now calculate the moments for a drop in temperature of $30^\circ F$. The moments for a rise in temperature by the same amount, will be equal in magnitude but opposite in sign.

(1) *Moments due to movement of column head G to the right.*

Movement of column head to the right due to a fall in temperature of $30^\circ F = \Delta l = 100 \times 30 \times {\cdot}000006 = 0{\cdot}018$ feet.

Moment at base of column '2' $= M_u = \dfrac{-\Delta l}{\beta_2 l_2} \cdot \dfrac{a_2}{l_2 - a_2 - b_2}$

$$= \frac{-0{\cdot}018 \times 5{\cdot}19 \times 128571 \times 0{\cdot}035}{3{\cdot}00 \times 18{\cdot}00 \times 7{\cdot}68}$$

$$= -1{\cdot}012 \text{ foot tons.}$$

Moment at top of column '2' =

$$M_0 = +M_u \times \frac{b_2}{a_2}$$

$$= +1{\cdot}012 \times \frac{5{\cdot}13}{5{\cdot}19}$$

$$= +1{\cdot}000 \text{ foot tons.}$$

The moments transferred into other members are drawn graphically (vide Drawing No. 4).

(2) *Moments due to movement of column head H to the right.*

Movement of column head to the right due to a fall in temperature of $30°F = \Delta l = 90 \times 30 \times {\cdot}000006 = 0{\cdot}0162$ feet.

Moment at base of column '3' =

$$M_u = \frac{-\Delta l}{\beta_3 l_3} \cdot \frac{a_3}{l_3 - a_3 - b_3}$$

$$= \frac{-0{\cdot}0162 \times 5{\cdot}08 \times 128571 \times 0{\cdot}035}{2{\cdot}95 \times 17{\cdot}67 \times 7{\cdot}51}$$

$$= -0{\cdot}945 \text{ foot tons.}$$

Moment at top of Column '3' =

$$M_0 = +M_u \times \frac{b_3}{a_3}$$

$$= +0{\cdot}945 \times \frac{5{\cdot}08}{5{\cdot}08}$$

$$= +0{\cdot}945 \text{ foot tons.}$$

As before, the moment diagram on this account has been constructed graphically on separate drawing No. 4.

(3) *Moments due to movement of Column head I to the right.*

Movement of Column head to the right due to a fall in temperature of $30° F = \Delta l = 80 \times 30 \times {\cdot}000006 = 0{\cdot}0144$ feet.

Moment at base of Column '4' =

$$M_u = -\frac{\Delta l}{\beta_4 l_4} \cdot \frac{a_4}{l_4 - a_4 - b_4}$$

$$= \frac{-0{\cdot}0144 \times 4{\cdot}97 \times 128571 \times 0{\cdot}035}{2{\cdot}89 \times 17{\cdot}33 \times 7{\cdot}39}$$

$$= -0.868 \text{ foot tons.}$$

Moment at top of Column '4'

$$M_0 = +M_u \times \frac{b_4}{a_4}$$

$$= +0{\cdot}868 \times \frac{4{\cdot}97}{4{\cdot}97}$$

$$= +0{\cdot}868 \text{ foot tons.}$$

In this case also the moment diagrams have been constructed graphically (vide Drawing No. 4).

As we are considering the first two openings only, the movements of other column beyond '4' will have very little effect on the portion of the structure we are concerned with.

The nett temperature moments have been obtained by algebraic summation of the moments due to the above three cases.

MOMENTS DUE TO BRAKING EFFECTS.

The force P_1 due to braking parallel to the surface of the road is given by

$$P_1 = Q(\mu_1 \pm \tan\alpha) \pm G \tan \alpha$$

Where Q = weight of the tractor

μ_1 = coefficient of friction between road surface and rolling wheel = 1/50 approximately in this case.

α = angle of inclination of the road surface with the horizontal $= \frac{1}{30}$

G = weight of the trailer.

In our case, since the speed of the steam roller is very small, the braking effect will be negligible. Hence we shall consider a line of 6 ton lorries. In a length of 110 ft. along the roadway we can possibly have 4 lorries in each traffic lane of 9 feet. Supposing the brake is applied to all of them at the same time, the force parallel to the road surface

$$P_1 = Q(\mu_1 + \tan\alpha)$$

$$= 4 \times 6\left(\frac{1}{50} + \frac{1}{30}\right)$$

$$= 4 \times 6 \times \frac{8}{150} = 1{\cdot}28 \text{ tons.}$$

Considering a strip of the structure, 1 foot wide, this force $= \frac{1{\cdot}28}{9}$

$$= 0{\cdot}142 \text{ ton.}$$

This load is resisted by 11 columns and assuming the resistance of all columns to be equal, load to be resisted by each =

$$P = \frac{0{\cdot}142}{11} = 0{\cdot}013 \text{ ton.}$$

1. *Moments in Column 2 :—*

Moment at base of column =

$$M_u = -P.l_2 \times \frac{a_2}{a_2 + b_2}$$

$$= -0{\cdot}013 \times 18{\cdot}00 \times \frac{5{\cdot}19}{10{\cdot}32}$$

$$= -0{\cdot}118 \text{ foot tons.}$$

Moment at top of column =

$$M_0 = +P.l_2 \times \frac{b_2}{a_2+b_2}$$

$$= +0{\cdot}013 \times 18{\cdot}00 \times \frac{5{\cdot}13}{10{\cdot}32}$$

$$= +0{\cdot}116 \text{ foot tons.}$$

Due to rigidity these moments in the column will be transferred into other members (vide Drawing No. 4).

2. *Moments in Column 3:—*

In this case since $a=b$,

Moment at base $= M_u = -\frac{Pl_3}{2} = -\frac{0{\cdot}013 \times 17{\cdot}67}{2}$

$= -0{\cdot}115$ foot tons.

Moment at top $= M_0 = +\frac{Pl_3}{2} = +0{\cdot}115$ foot tons.

3. *Moments in column 4:—*

Here also, since $a=b$

Moment at base $= M_u = -\frac{Pl_4}{2} = -\frac{0{\cdot}013 \times 17{\cdot}33}{2}$

$= -0{\cdot}113$ foot tons.

Moment at top $= M_0 = +\frac{Pl_4}{2} = +0{\cdot}113$ foot tons.

The effects of temperature and braking are exactly similar and hence instead of considering the two effects separately we can combine them before drawing the moment diagrams graphically. Hence we shall have to consider the following cases for constructing the moment diagrams. The nett diagram is obtained by algebraic summation of the individual diagrams.

Column No.	Base or Top.	Moment due to temperature (foot tons)	Moment due to braking effects (foot tons)	Total moments. (foot tons)
Column '2'	Base	−1·012	−0·118	−1·130
	Top	+1·000	+0·116	+1·116
Column '3'	Base	−0·945	−0·115	−1·060
	Top	+0·945	+0·115	+1·060
Column '4'	Base	−0·868	−0·113	−0·981
	Top	+0·868	+0·113	+0·981

MOMENTS

Due to Temperature and Braking Effects.

Section.	Moments (foot tons) due to drop in temperature of 30°*F* together with braking effects.	Moments (foot tons) due to a rise in temperature of 30°*F* together with braking effects.
A_1	—0·04	+0·04
F_1	nil	nil
B_2	−1·25	+1·25
G_2	+1·20	−1·20
C_3	−1·24	+1·24
H_3	+1·24	−1·24
F_6	nil	nil
$F_6^{\frac{1}{2}}$	−0·10	+0·10
F_6G	−0·20	+0·20
$G_6^{\frac{1}{2}}$	−0·30	+0·30
G_6	−0·40	+0·40
G_7	+0·80	−0·80
$G_7^{\frac{1}{2}}$	+0·44	−0·44
G_7H	+0·08	−0·08
$H_7^{\frac{1}{2}}$	−0·29	+0·29
H_7	−0·65	+0·65
A_{11}	−0·13	+0·13
$A_{11}^{\frac{1}{2}}$	+0·02	−0·02
$A_{11}B$	+0·17	−0·17
$B_{11}^{\frac{1}{2}}$	+0·32	−0·32
B_{11}	+0·47	−0·47
B_{12}	−0·78	+0·78
$B_{12}^{\frac{1}{2}}$	−0·43	+0·43
$B_{12}C$	−0·07	+0·07
$C_{12}^{\frac{1}{2}}$	+0·29	−0·29
C_{12}	+0·64	−0·64

N. B.—The moments for a rise in temperature of 30°*F* will be opposite in sign but equal in magnitude to those for a drop in temperature by the same amount Due to the slope of the roadway the moments due to braking effects will be slightly different depending on the direction of the movement of the lorries. But this difference being very small, the total moments may be taken to be equal in magnitude in both cases.

TABLE OF TOTAL MOMENTS

FOR HORIZONTAL MEMBERS

Section	Maximum positive moment (foot tons.)				Maximum negative moment (foot tons.)			
	Dead Load Moment	Live Load Moment	Moment due to Temp. and Braking	Total Maximum positive moment	Dead Load Moment	Live Load Moment	Moment due to Temp. and Braking	Total Maximum negative moment
F_6	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
$F_6^{\frac{1}{2}}$	0·40	2·22	0·10	2·72	−0·40	0·20	0·10	−0·10
F_6 G	0·43	2·48	0·20	3·11	−0·43	0·40	0·20	0·17
$G_6^{\frac{1}{2}}$	0·07	1·44	0·30	1·81	−0·07	0·60	0·30	0·83
G_6	−0·70	0·16	0·40	−0·14	0·70	1·98	0·40	3·08
G_7	−0·67	0·28	0·80	0·41	0·67	1·74	0·80	3·21
$G_7^{\frac{1}{2}}$	−0·03	1·48	0·44	1·89	0·03	0·77	0·44	1·24
G_7 H	0·21	2·12	0·08	2·41	−0·21	0·38	0·08	0·25
$H_7^{\frac{1}{2}}$	0·07	1·44	0·29	1·80	−0·07	0·60	0·29	0·82
H_7	−0·46	0·38	0·65	0·57	0·46	1·65	0·65	2·76
A_{11}	−1·40	0·23	0·13	−1·04	1·40	1·04	0·13	2·57
$A_{11}^{\frac{1}{2}}$	0·10	0·74	0·02	0·86	−0·10	0·61	0·02	0·53
A_{11} *B*	0·62	1·31	0·17	2·10	−0·62	0·30	0·17	−0·15
$B_{11}^{\frac{1}{2}}$	0·18	0·61	0·32	1·11	−0·18	0·51	0·32	0·65
B_{11}	−1·21	0·31	0·47	−0·43	1·21	1·33	0·47	3·01
B_{12}	−1·29	0·26	0·78	−0·25	1·29	1·22	0·78	3·29
$B_{12}^{\frac{1}{2}}$	0·14	0·64	0·43	1·21	−0·14	0·56	0·43	0·85
B_{12} C	0·61	1·26	0·07	1·94	−0·61	0·27	0·07	−0·27
$C_{12}^{\frac{1}{2}}$	0·14	0·62	0·29	1·05	−0·14	0·52	0·29	0·67
C_{12}	−1·27	0·28	0·64	−0·35	1·27	1·26	0·64	3·17

DESIGN DATA FOR COLUMNS.

The columns being symmetrically reinforced, only the magnitude of the maximum moment, irrespective of the sign, is necessary.

Section.	Dead Load Effects.		Live Load Effects.		Temp. and Braking Effects.		Design data No. 1 Dead Load+Live Load +temp. and braking.		Design data No. 2 Dead Load+temp. & braking.	
	Moment (foot tons)	Corresponding Thrust (tons)	Moments (foot tons)	Corresponding thrust (tons)	Moments (foot tons)	Corresponding thrust (tons)	Total Moment (foot tons)	Corresponding thrust (tons)	Total Moment (foot tons)	Corresponding thrust (tons)
A_1	nil	1·374	+0·12	0·786	±0·04	negligible	0·16	2·160	0·04	1·374
			−0·12	0·786						
F_1	nil	0·486	nil	..	nil	..	nil	0·486	nil	0·486
B_2	+0·03	1·585	+0·21	0·786	±1·25	negligible	1·49	2·371	1·28	1·585
			−0·25	0·786						
G_2	−0·04	0·715	+0·62	0·786	±1·20	,,	1·78	1·501	1·24	0·715
			−0·52	0·786						
C_3	nil	1·458	+0·20	0·786	±1·24	,,	1·44	2·244	1·24	1·458
			−0·20	0·786						
H_3	nil	0·605	+0·50	0·786	±1·24	,,	1·74	1·391	1·24	0·605
			−0·50	0.786						

DESIGN OF COLUMNS.

The columns are to be designed for bending moment combined with direct thrust. For this purpose we shall use the method as given by Mörsch (Entwurf und Berechnung von Eisenbetonbauten—Band I-pages 235 to 269) and use his curves.

The design data for which the sections are to be designed are given in the table on page 125. Each section is to be designed for two alternative cases in order to find out the worst one.

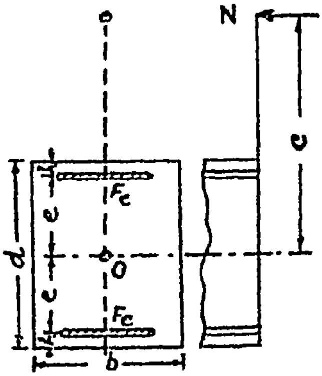
COLUMN (1)

Section A_1—

(1) Bending moment $M = 0{\cdot}16$ foot tons.

Corresponding thrust $N = 2{\cdot}160$ tons.

All the members are 9″ thick. Deducting 1″ for cover (upto centre of reinforcement), and using the same notations as Mörsch.



$$c = 4{\cdot}5 - 1 = 3{\cdot}5''.$$

$$d = 9''.$$

$$e = \frac{3{\cdot}5}{9}d = 0{\cdot}39\ d.$$

We shall therefore use curves for $e = 0{\cdot}42\ d$ and then make the necessary approximate corrections later on.

$$\text{Eccentricity } e = \frac{M}{N} = \frac{0{\cdot}16 \times 12}{2{\cdot}16} = 0{\cdot}9\ ''$$

Thus the resultant passes through the middle third and hence no tension will be developed.

$$\text{Direct stress} = +\frac{2{\cdot}16 \times 2240}{9 \times 12} = +44{\cdot}8 \text{ pounds per square inch.}$$

Section modulus Z of the Section

$$= \frac{bd^2}{6} = \frac{12 \times 81}{6} = 162 \text{ in.}^3$$

$$\therefore \quad \text{bending stress} = \pm\frac{M}{Z} = \frac{0{\cdot}16 \times 12 \times 2240}{162}$$

$$= \pm 26{\cdot}6 \text{ pounds per square inch.}$$

$\therefore$ maximum stress $= +(44{\cdot}8 + 26{\cdot}6) = +71{\cdot}4$ pounds per square inch.

and minimum stress $= +(44{\cdot}8 - 26{\cdot}6) = +18{\cdot}2$ pounds per square inch.

The stresses are thus very low and theoretically no reinforcement is necessary.

COLUMN—(2)

Section B_2 :—

(1) $\left.\begin{array}{l} M=1\cdot49 \text{ foot tons} \\ N=2\cdot371 \text{ tons}\end{array}\right\}$

We shall design the section using curves 81 (Mörsch) *i.e.* with symmetrical reinforcement.

where $e=0\cdot42\,d$

$\sigma_e=1200 \text{ kg/cm}^2$ or 17050 lbs/in^2.

$$\frac{M}{bd^2}=\frac{1\cdot49\times12\times2240}{12\times81}=41\cdot2 \text{ lbs/sq. in.}$$

$$=2\cdot9 \text{ kg/cm}^2.$$

$$\frac{N}{bd}=\frac{2\cdot371\times2240}{12\times9}=49\cdot7 \text{ lbs/sq. in.}$$

$$=3\cdot49 \text{ kg/cm}^2.$$

Using curves 81,

σ_b = stress in concrete $=34\cdot5 \text{ kg/cm}^2$.

$=490$ lbs./sq. in.

$\mu=0\cdot15$ per cent.

$$\therefore\quad F_e=F'_e=\mu bd=\frac{0\cdot15\times12\times9}{100}$$

$=0\cdot162$ square inches.

With steel stress at 16000 lbs/sq. in. and $e=0\cdot39d$, $F_e=F'_e\sim0\cdot162\times\frac{17050}{16000}\times\frac{0\cdot42}{0\cdot39}=0\cdot186$ square inches.

Hence we see that at section B_2 with design data No. 1 we require 0·186 square inches of steel on each face.

(2) $\left.\begin{array}{l} M=1\cdot28 \text{ foot tons.} \\ N=1\cdot585 \text{ tons}\end{array}\right\}$

Using curves 81 *i.e.*, with symmetrical reinforcement—

$$\frac{M}{bd^2}=\frac{1\cdot28\times12\times2240}{12\times81}=35\cdot4 \text{ lbs./sq. in.}$$

$$=2\cdot49 \text{ kg/cm}^2$$

$$\frac{N}{bd}=\frac{1\cdot585\times2240}{12\times9}=32\cdot9 \text{ lbs./sq. in.}$$

$$=2\cdot31 \text{ kg/cm}^2$$

From curves,

σ_b = stress in concrete $=29\cdot5 \text{ kg/cm}^2$

$=420$ lbs./sq. in.

$\mu=0\cdot15$ per cent.

$F_e = F'_e = \mu bd$

$= \dfrac{0{\cdot}15 \times 12 \times 9}{100} = 0{\cdot}162$ square inches.

The above area is obtained on assuming steel stress = 1200 kg/cm^2 or 17050 lbs/sq. in. and $e = 0{\cdot}42\,d$,

$\therefore$ with steel stress at 16000 lbs/sq. in. and $e = 0{\cdot}39\,d$,

$F_e = F_e' \sim 0{\cdot}162 \times \dfrac{17050}{16000} \times \dfrac{0{\cdot}42}{0{\cdot}39} = 0{\cdot}186$ square inches.

Therefore according to design data No. 2, we require 0·186 square inches of steel on each face.

Taking the two cases into consideration (data no. 1 & 2) we require 0·186 square inches of steel on each face, at Section B_2

Section G_2 :—

(1) $\left.\begin{aligned} M &= 1{\cdot}78 \text{ foot tons.} \\ N &= 1{\cdot}501 \text{ tons.}\end{aligned}\right\}$

Using curves 81 (Mörsch) with symmetrical reinforcement, where $e = 0{\cdot}42\,d$

and $\sigma_e = 1200$ kg/cm^2 or 17050 lbs./in.^{2}

$\dfrac{M}{bd^2} = \dfrac{1{\cdot}78 \times 12 \times 2240}{12 \times 81} = 49{\cdot}2$ lbs./in^2.

$= 3{\cdot}47$ kg/cm^2.

$\dfrac{N}{bd} = \dfrac{1{\cdot}501 \times 2240}{12 \times 9} = 31{\cdot}1$ lbs./in^2.

$= 2{\cdot}19$ kg/cm^2.

Using curve no. 81,

σ_b = stress in concrete = 32·5

μ = 0·255 per cent.

$F_e = F_e' = \mu bd = \dfrac{0{\cdot}255 \times 12 \times 9}{100} = 0{\cdot}275$ square inches.

With steel stress at 16000 lbs/sq. in. and $e = 0{\cdot}39\,d$,

$F_e = F_e' \sim 0{\cdot}275 \times \dfrac{17050}{16000} \times \dfrac{0{\cdot}42}{0{\cdot}39} = 0{\cdot}316$ square inches

From the above calculations we see that according to design data No. 1, at section G_2 we require 0·316 square inches on each face, per foot-strip of wall.

We shall now calculate the reinforcements according to design data No. 2.

(2) $\left.\begin{aligned} M &= 1{\cdot}24 \text{ foot tons.} \\ N &= 0{\cdot}715 \text{ tons.}\end{aligned}\right\}$

(*a*) Using curves 81, for symmetrical reinforcement,

$$\frac{M}{bd^2}=\frac{1{\cdot}24\times12\times2240}{12\times81}=34{\cdot}3 \text{ lbs/in}^2.$$

$$=2.42 \text{ kg/cm}^2$$

$$\frac{N}{bd}=\frac{0{\cdot}715\times2240}{12\times9}=14{\cdot}8 \text{ lbs./in}^2.$$

$$=1{\cdot}04 \text{ kg/cm}^2.$$

From curves 81,

σ_b = stress in concrete = 26 kg/cm^2 = 327 lbs./in^2.

μ = 0·2 per cent.

$$F_e=F_e'=\mu bd=\frac{0{\cdot}2\times12\times9}{100}=0{\cdot}216 \text{ square inches.}$$

With steel stress at 16000 lbs/in.^{2} and $e=0{\cdot}39\,d$,

$$F_e=F_e' \backsim 0{\cdot}216\times\frac{17050}{16000}\times\frac{0{\cdot}42}{0{\cdot}39}= 0{\cdot}248 \text{ square inches.}$$

Taking the two cases into consideration (data no. 1 and 2) we require at section G_2, 0·312 square inches of steel on each face of the wall.

DESIGN OF
TOP HORIZONTAL MEMBERS

MEMBER (6)

(*a*) *Section at a distance of 4 feet from 'F':—*

Maximum moment = +3·27 foot tons per foot strip of slab.

Total thickness of slab = 9″

Deducting 1″ for cover upto centre of reinforcement, effective depth $d=9-1=8''$

$$\therefore \frac{M}{bd^2}=\frac{3{\cdot}27\times12\times2240}{12\times64}=114{\cdot}5 \text{ pounds per square inch.}$$

From slide rule, stressing the steel to 16000 pounds per square inch.

Stress in concrete = 670 pounds per square inch.

and μ = percentage of steel = 0·828

$\therefore$ area of steel $=A_t=\mu bd$

$$=\frac{0{\cdot}828\times12\times8}{100}$$

= 0·795 square inches.

(*b*) *Section at a distance of* 1′-4½″ *from G, i.e., just at the end of the haunch :—*

Maximum moment = −1·6 foot tons.

$$\frac{M}{bd^2}=\frac{1{\cdot}6\times12\times2240}{12\times64}= 56 \text{ pounds per square inch.}$$

From slide rule stressing the steel to 16000 pounds per square inch.

Stress in concrete = 430 pounds per square inch.

$$\mu = 0{\cdot}39 \text{ per cent.}$$

$$A_t = \frac{0{\cdot}39 \times 12 \times 8}{100}$$

$$= 0{\cdot}375 \text{ square inches.}$$

MEMBER (7)

(a) Section at the centre of the span :—

Maximum moment = $+2{\cdot}41$ foot tons.

$$\frac{M}{bd^2} = \frac{2{\cdot}41 \times 12 \times 2240}{12 \times 64} = 84{\cdot}5 \text{ pounds per square inch.}$$

From slide rule, stressing the steel to 16000 pounds per square inch.

Stress in concrete = 550 pounds per square inch.

$$\mu = 0{\cdot}602 \text{ per cent.}$$

$$\therefore \quad A_t = \frac{0{\cdot}602 \times 12 \times 8}{100} = 0{\cdot}577 \text{ square inches.}$$

(*b*) *Section at a distance of* 1′-4½″ *from G, i. e., just at the end of the haunch* :—

Maximum moment = $-2{\cdot}12$ foot tons.

$$\frac{M}{bd^2} = \frac{2{\cdot}12 \times 12 \times 2240}{12 \times 64} = 74{\cdot}2 \text{ pounds per square inch.}$$

From slide rule, stressing the steel to 16000 pounds per square inch.

Stress in concrete = 510 pounds per square inch.

$$\mu = 0{\cdot}525 \text{ per cent.}$$

$$\therefore A_t = \frac{0{\cdot}525 \times 12 \times 8}{100} = 0{\cdot}504 \text{ square inches.}$$

(*c*) *Section at a distance of* 1′-4½″ *from H, i. e.. just at the end of the haunch* :—

Maximum moment = $-1{\cdot}65$ foot tons.

$$\frac{M}{bd^2} = \frac{1{\cdot}65 \times 12 \times 2240}{12 \times 64} = 57{\cdot}8 \text{ pounds per square inch.}$$

From slide rule, stressing the steel to 16000 pounds per square inch.

Stress in concrete = 440 pounds per square inch.

$$\mu = 0{\cdot}4 \text{ per cent.}$$

$$\therefore \quad A_t = \frac{0{\cdot}4 \times 12 \times 8}{100} = 0.384 \text{ square inches.}$$

DESIGN OF BOTTOM HORIZONTAL MEMBERS

Member—(11).

(*a*) *Section at a distance of* 1′ − 4½″ *from 'A' i.e. just at the end of the haunch* :—

Maximum moment = −1·35 foot tons.

$$\frac{M}{bd^2}=\frac{1{\cdot}35\times12\times2240}{12\times64}=47{\cdot}3 \text{ pounds per square inch.}$$

From slide rule, stressing the steel to 16000 pounds per square inch.

Stress in concrete = 386 pounds per square inch.

$\mu = 0{\cdot}326$ per cent.

$$\therefore\quad A_t=\frac{0{\cdot}326\times12\times8}{100}=0{\cdot}313 \text{ square inches.}$$

(*b*) *Section at the centre of the span* :—

Maximum moment = +2·10 foot tons.

$$\frac{M}{bd^2}=\frac{2{\cdot}10\times12\times2240}{12\times64}=73{\cdot}5 \text{ pounds per square inch.}$$

From slide rule, stressing the steel to 16000 pounds per square inch.

Stress in concrete = 505 pounds per square inch.

$\mu = 0{\cdot}518$ per cent.

$$\therefore\quad A_t=\frac{0{\cdot}518\times12\times8}{100}=0{\cdot}498 \text{ square inches.}$$

(*c*) *Section at a distance of* 1′ −4½″ *from B, i.e., just at the end of the haunch*:—

Maximum moment = − 1·55 foot tons.

$$\frac{M}{bd^2}=\frac{1{\cdot}55\times12\times2240}{12\times64}=54{\cdot}4 \text{ pounds per square inch.}$$

From slide rule, stressing the steel to 16000 pounds per square inch.

Stress in concrete = 422 pounds per square inch.

$\mu = 0{\cdot}378$ per cent.

$$\therefore\quad A_t=\frac{0{\cdot}378\times12\times8}{100}=0{\cdot}363 \text{ square inches.}$$

Member—(12)

(*a*) *Section at a distance of* 1′ −4½″ *from B, i.e., just at the end of the haunch*:—

Maximum moment = −1·87 foot tons.

$$\frac{M}{bd^2}=\frac{1{\cdot}87\times12\times2240}{12\times64}=65{\cdot}5 \text{ pounds per square inch.}$$

From slide rule, stressing the steel to 16000 pounds per square inch.

Stress in concrete = 472 pounds per square inch.

$\mu = 0{\cdot}455$ per cent.

$$\therefore\quad A_t=\frac{0{\cdot}455\times12\times8}{100}=0{\cdot}437 \text{ square inches.}$$

(*b*) *Section at the centre of the span:—*

Maximum moment $= +1.94$ foot tons.

$$\frac{M}{bd^2} = \frac{1.94 \times 12 \times 2240}{12 \times 64} = 68 \text{ pounds per square inch.}$$

From slide rule, stressing the steel to 16000 pounds per inch.

Stress in concrete $= 482$ pounds per square inch.

$\mu = 0.473$ per cent.

$$A_t = \frac{0.473 \times 12 \times 8}{100} = 0.454 \text{ square inches.}$$

(*c*) *Section at a distance of* $1' - 4\frac{1}{2}''$ *from C, i.e., just at the end of the haunch:—*

Maximum moment $= -1.64$ foot tons.

$$\frac{M}{bd^2} = \frac{1.64 \times 12 \times 2240}{12 \times 64} = 57.5 \text{ pounds per square inches.}$$

From slide rule, stressing the steel to 16000 pounds per inches.

Stress in concrete $= 435$ pounds per square inches.

$\mu = 0.396$ per cent.

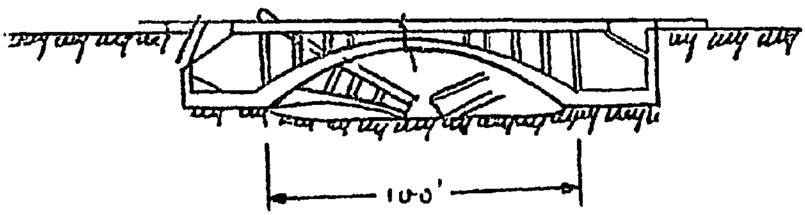
$$\therefore \quad A_t = \frac{0.396 \times 12 \times 8}{100} = 0.38 \text{ square inches.}$$

CORRESPONDENCE

Comments by Dr. M. A. Korni (Calcutta).

Mr. Chambers admits that the collapse of the 100 feet span open spandrel arch bridge, was due unfortunately to the type of bridge which was selected and designed But he does not tell us why this particular type of bridge proved to be so unfortunate, seeing that he is completing a similar bridge over the Teesta River some 14 miles distant, where the river conditions are exactly the same ; *e.g.*, the hill-stream effects, such as the rapid rise of the water (which is often as much as 25 feet within two hours) and the abundance of floating timber. Mr. Chambers' answer to this point will, I am sure, be that, although the superstructure of these two bridges are the same, the *foundations* of the Sevoke Bridge were different.

The foundation of the Sevoke Bridge was a shallow and hollow system which could be adopted for a road bridge in a town somewhere in Europe, perhaps, where the rivers are, for the most part, harnessed. A great deal of expense would have been saved if the authorities had at their disposal the services of a consulting engineer with experience in bridge building. It was evident that the only fixity of such an abutment depends merely on the *friction* between the bottom of the abutment and the river bed. The amount of friction was borne out by the weight of the earth filling. As soon as the earth filling was washed away, the thrust of the arch moved the abutment and the bridge toppled as illustrated in sketch below.



In drawing No. 1, showing the site plan, without scale or other explanatory references, it will be noted that the unfortunate 100 feet arch bridge was connected with a high embankment. This embankment without culverts or other outlets had practically barraged the flow of several rivers, jhoras, etc. Although the author had a strong warning at the time of construction, when the staging was completely washed away, this did not prove to be a lesson to him, and neither was it the first; for at the time of the construction of the Anderson Bridge over the Teesta, he built a 70 feet span bridge on the same river, traces of which could not be found after a flood which occurred shortly following its completion. The reason for this was perfectly clear, but the strong forces of Nature were blamed. We always learn by our mistakes, and the mistakes in this case were not made from a lack of knowledge of how to deal with stresses due to vertical loads, for these matters are dealt with sufficiently in text books. But these mistakes were due to the lack of a careful analyses of the Natural

Forces as borne out by the local conditions and these are not found in any text books. There are reinforced concrete bridges built in India like the Nerbudda Bridge which is submersible to a depth of over 40 feet above its bridge level and when the flood subsides, the bridge although found to be loaded with trees remains undamaged. This is not a result of luck, but due to the foresight of the designer who took all the severe natural forces into consideration.

Although I, personally, did not witness the action and position of the collapse of the bridge, the description tallies with the forecast I made in a private letter to Mr. G. Walton, Chief Engineer of Messrs. Bird & Co., before the collapse of the bridge, see sketch on page 133.

I would also like to mention that Mr. Chambers had put forward another type of bridge which was not accepted by the Chief Engineer of the department. This design was similar to a bridge built by Mr. Chambers, over a "jhora" near the Teesta Bridge. This "jhora" bridge has been perfectly satisfactory although the stream is very unruly.

Mr. Chambers has put up a new bridge according to drawing No. 5, and claims that the following conditions were considered when designing.

(1) Stabilisation of the stream.

(2) A possible stoppage of timber.

(3) Cheapness.

The author has drawn a veil over the third item by telling us that the cost per square foot of elevation area (between the road level and the bottom of the foundation) has amounted to an average of Rs. 72/-. Calculating, we find, that the elevation area is $340 \times 32 = 10,880$ square feet and at Rs. 72/- per square foot the cost works to Rs. 7,83,360/-. This is an exorbitantly costly bridge! A normal bridge of 10 feet spans, 18 feet wide and 340 feet long, with roadway, approaches, foundations, etc., would have cost Rs. 61,200/- only. We may say 1 lakh, but not 8 lakhs! Let us assume that I misunderstood what was meant by the author as a Front Elevation Area and let us subtract the openings which are $21 \times 10 \times 34$ or 7,140 square feet. $(10,880 - 7,140) \times 72 =$ Rs. 2,69,280/-. Even that figure is exorbitant. I am sure everyone will agree with this statement.

The design is an exceptional example of a bridge which will appear strange and revolting to most of us. From the drawing, it appears to be a double-decked construction, one deck serving as a foundation slab. This reminds me of the Vierendel System, where the shear forces are very active and predominant, and many bridges of this type, even those built in steel, have failed totally.

At a glance, the live and dead load bending diagram in Drawing No. 2 and No. 3 creates a satisfactory feeling, and this is as long as the 10 feet box foundation or cofferdam foundation, as the author calls it, is resting on the river bed. Let us imagine a scour under the bottom deck of the bridge somewhere about the middle, which will probably occur some day. After all, a scour of 10 feet in a river which is blocked by piers every 10 feet, working out to 24 feet less passage way from a 330 feet free span and resulting in about 7.2% obstruction is not improbable. In such a case,

then, this system will be converted into a pure Vierendel Bridge and the diagram of shear as shown in the sketch opposite showing tremendous shear in the columns is not a pleasant one. The Negative Bending Moment at the bottom slab, which was so useful for diminishing the Positive Bending Moment at the top slab, will be converted into a positive one, increasing the total Positive Bending Moment at the top with all the severe consequences of a tremendous shear.

We must give the author the credit of dealing thoroughly and scientifically with the designs, a thing which so many engineers in India are frightened of doing and we are much obliged to him for showing us the Suter methods of analysing a multiple frame construction which is very interesting indeed.

But to arrive at a Bending Moment of 2.72 foot tons or 731,136 foot lbs. a much easier method could be followed, namely the Column analogy method, which, though not a precise, analytical method, is still exact enough for a bridge construction of 10 feet spans. Even exact analyses are based on some assumptions which are not quite in accordance with the facts. For example, "E" in concrete is a purely conjectural figure. It may be 2,000,000 or 3,000,000 pounds per square inch just as you like. Moment of Inertia "I" also lacks exact determination in concrete. In some cases, it is advisable to work with an "I" of concrete only, or with an equivalent area of steel. From this, however, it does not follow that the conclusions of exact analysis are of no use or that they do not approach the facts. But a display of calculation based on Suter's analysis, which is very impressive, should really be used on bridges with a greater span than 10 feet.

The author had taken in his calculations as important factors which affect the Bending Moments, the temperature and the braking affects. The variations of temperature have been taken as $\pm 30°$F. The Indian Roads Congress Standard Specifications prescribe a temperature range of 150 degrees Fahrenheit, (vide clause B 9* page 16). Yet inspite of this, the author arrives at a total Maximum Bending Moment due to temperature and braking, of 0.8 in a member called G_7 (vide page 123) while Maximum Bending Moment for dead and live load in a member F_6 G is equal to 2.91 foot tons (vide page 124). This means that the braking and temperature effects are about 36%. If this is so, what will the additional Bending Moment due to wind, seismic forces and water pressure (which have not been taken into consideration) be. Why has the author not taken these into consideration? If a bridge system involves 36% moments due to temperature and braking effects alone, even in one member, it is certainly not an economical one.

Important and very instructive items such as the stabilisation of the stream and the minimization of floating trees, timber, etc., which float down in the monsoon in enormous bulk, have not been discussed by the author. Have these items been considered in the design, at all? If so, I do think that all Members of the Roads Congress will be indebted to the author if he would describe them as minutely as he did the Suter analysis.

In conclusion, I must thank the author for his very interesting paper.

*Standard Specification and Codes of Practice for Road Bridges in India, (1937).
Indian Roads Congress, New Delhi.

Comments by Mr. E. P. Nicolaides (Bombay).

Both in conception and design, the Sevoke Bridge is certainly unusual and I should like to thank Mr. Chambers for the trouble he has taken to write for us a paper on the subject. The author is so well known to bridge engineers and has already to his credit so much interesting work for the cause of reinforced concrete bridges in India that praise from me will add very little indeed to his fame. I trust he will permit me, however, a few criticisms on his paper which I put forward with the hope that the ensuing discussion may add something more to our knowledge of reinforced concrete bridge design.

Cost of Bridge. The author has claimed that this design was an economical one; yet his statement does not seem to be confirmed by the cost rate of Rs. 72/- per square foot of bridge elevation given at the bottom of page 92 of the paper. The average height from the bottom of foundations to top of decking is 30 feet so that the rate per running foot of bridge works out at Rs. $72 \times 30 = 2{,}160$/- which is exorbitant A rate ten times smaller *i. e.,* Rs. 216/- per running foot would be normal for a bridge on such a site.

Foundations. From the structural features, the design of the foundations will be of particular interest to bridge engineers on account of their shallow depth in a sandy bed where scouring action may occur and may reach depths greater than the foundations.

It is true that the continuity of the foundations offers a certain amount of safety against local scour, since—as pointed out by the author on page 91 of the paper—the cofferdam walls are capable of acting as a beam spanning the scoured gap.

On the other hand, it may be mentioned that, whereas the strength of the cofferdam walls is limited and can be estimated by the usual methods of design, the length over which scour may occur is definitely unknown and it may vary from nothing to as much as a hundred feet and over, in the 300 feet wide river bed of loose sand.

The expansion joints provided in the decking limit the depth of the foundation beam effect to the depth of the cofferdam wall only, *i.e*, to 10 feet.

Referring to page 111 of the paper the load carried per running foot of each longitudinal wall is found as follows:—

Dead Load of deck slab, $\frac{1}{2} \times 140 \times 20$	$= 1400$ lbs/ft.
Dead Load of coping and railing, say	$= 50$ lbs/ft.
Weight of pier wall, $\frac{1}{2} \times 1920 \times \frac{20}{10}$	$= 1920$ lbs/ft.
Weight of bottom slab, $10 \times 0.75 \times 1 \times 150$	$= 1125$ lbs/ft.
Weight of longitudinal cofferdam wall, $9.25 \times 0.75 \times 1 \times 150$	$= 1040$ lbs/ft.
Weight of cross diaphgram, $\frac{1}{2} \times 9.25 \times 0.75 \times 1 \times 150 \times \frac{18.5}{10}$	$= 965$ lbs/ft.

$$\text{Total dead load per foot run} = 6500 \text{ lbs.}$$

For the live load, take approximately

100 lbs/sq. ft., *i.e.*, $\frac{1}{2} \times 100 \times 20 = 1000$ lbs.

$$\text{Total dead plus live load per foot run} = 7500 \text{ lbs.}$$

When scour occurs over a length L, it can be taken that the cofferdam wall will act as a fixed end beam spanning the gap L and carrying the above loads.

The maximum negative bending moment at the fixed ends will be:

$$\frac{7500 \times L^2}{12}$$

On the other hand, the resistance moment of the concrete in the 120″ deep × 9″ wide beam formed by the cofferdam wall is

$$135 \times 9 \times 115^2 = 16,100,000 \text{ inch pounds.}$$

(the effective depth is taken as 115″ and the permissible stresses 750 lbs. and 16000 lbs/sq. in. with $m = 15$).

With this resistance moment, the maximum length L over which the cofferdam wall can span as a fixed end beam is given by the equation

$$\frac{7500L^2}{12} = 16,100,000 \text{ in. lbs. } i.e., \ L = 46 \text{ feet.}$$

Is it possible to predict with safety that the scoured length will not exceed at any time 46 feet?

It may be mentioned also that the tensile reinforcement required for this beam is:—

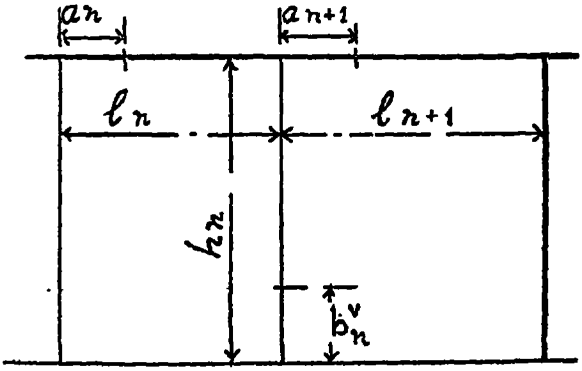
$$\frac{16,100,000}{16,000 \times 0.87 \times 115} = 10.1 \text{ square inches, say, 10 Nos } 1\ 1/8'' \text{ bars.}$$

And this does not appear to be provided as far as it can be seen from the detailed drawings attached to the paper.

Design of super-structure. The author has used a method of fixed points for designing the framed super-structure. As mentioned by the author on page 97 of the paper, this method assumes that movements of the joints are possible by rotation only and not by translation. This condition would be fulfilled in the case of a symmetrical structure symmetrically loaded; neither of these two conditions, however, are fulfilled by the structure under consideration and consequently the results obtained by the author are only approximate. The exact Elastic Theory applied to this type of framed structure leads to a series of simultaneous equations each containing four successive node moments. By a very simple grouping process of the unknown moments, these exact equations can be spilt into two groups of equations of

similar form to the well known equation of 3 moments of continuous beams and the resolution of the latter systems of equations does not entail more calculating work than the method given by the author.

Regarding the calculation of the fixed points, the formulae given by the author can be condensed into the following equation expressing the fact that there is no change of angle between the members adjoining on to a node.



$$\beta_n\left(3-\frac{l_n}{l_n-a_n}\right)\beta_{n+1}\left(3-\frac{l_{n+1}}{a_{n+1}}\right)$$
$$+\beta_n\left(3-\frac{l_n}{l_n-a_n}\right)\beta^v_n\left(3-\frac{h_n}{h_n-b_n}\right)$$
$$+\beta_{n+1}\left(3-\frac{l_{n+1}}{a_{n+1}}\right)\beta^v_n\left(3-\frac{h_n}{h_n-b^v_n}\right)=0$$

where $\beta_n=\frac{l_n}{6J_n}$; $\beta_{n+1}=\frac{l_{n+1}}{6J_{n+1}}$; $\beta^v_n=\frac{h_n}{6J_n}$

It will be noticed that this equation is a relation between three unknown lengths namely a_n, a_{n+1} and b^v_n and to find one of them say a_{n+1} it is necessary to fix, in advance, the values of the two others *i.e.*, a_n and b^v_n.

For this calculation the author has selected in advance the values of:—

$b_2=5.25$ ft.
$b_3=5.17$ ft.
$b_4=5.07$ ft.
$b_5=4.98$ ft.
and $a_{11}=2.40$ ft.

and from these values he has deduced, with the above formula, the distances of the fixed points

$a_{12}=2.46$ ft., $a_{13}=2.47$ ft., $a_{14}=2.47$ ft.

For the other points, a_{15} and further to the right, he accepts the same value of 2.47 feet and further he lays down $b_{15}=a_{15}=2.47$

on grounds of symmetry. This symmetry, however, does not appear to exist, since for the other frames to the right of number 15 (vide sketch on page 98 of the paper) the vertical posts continue to decrease in height from $h_5 = 17$ feet to $h = 15$ feet at the end of the continuous unit of eleven spans considered by the author. Having made this in-exact assumption of symmetry, the author proceeds to calculate backwards the values of:—

$a_5 = 4.86$ feet	$b_{14} = 2.48$ feet	$a_4 = 4.97$ feet
$b_{13} = 2.47$ feet	$a_3 = 5.08$ feet	$b_{12} = 2.47$ feet
$a_2 = 5.19$ feet	$b_{11} = 2.47$ feet	

At this stage, the author makes a third assumption of $\tau_{16}^{A} = \tau_{11}^{A}$ (vide page 105 of the paper) and on the strength of it, he calculates $a_1 = 5.30$ feet and checks the values for a_{11} and b_2 adopted at the beginning of the calculation.

The assumption of $\tau_{16}^{A} = \tau_{11}^{A}$ amounts to accepting $b_{11} = a_{16} = 2.47$ feet and I cannot see any reason for this assumption except that it helps to justify the value of $a_{11} = 2.40$ feet adopted by the author at the beginning.

The author's formulae can be used also to check the values of b_2, b_3, b_4, and b_5 but the results do not confirm in this case the values originally adopted by the author for these fixed points. In the same way, the fixed points in the top horizontal member of the frame calculated with the formulae and assumptions given in the paper will be found different from those of the bottom horizontal member.

As for the check for a_{11}, I find that this would give equally good results if one assumed at the beginning for b_2, b_3, b_4, and b_5 values different from those given by the author, namely $b_2 = 6$ feet, $b_3 = 5.8$ feet, $b_4 = 5.6$ feet, $b_5 = 5.4$ feet with $a_{11} = 2.40$ feet. On the whole the calculation of these fixed points appears to lack precision and requires a considerable amount of calculating work.

For the calculation of the bending moments, the author has given, on pages 96, and 97 of the paper, formulae relating to the moments in the various frame members joining on to a node. These formulae express the condition of equilibrium of the node *viz.* that the sum of the moments in all the members at the node must be nil. According to this condition, the dead load moments should satisfy the following relations at node G: (vide sketch on page 98 of the paper).

$$M_{G6} + M_{G2} = M_{G7}$$

In the table of dead load moments on page 112 of the paper the author gives $M_{G6} = -1560$ ft. lbs. $M_{G2} = -85$ ft. lbs. and in order to satisfy the above relation M_{G7} should be equal to $-1560 - 85 = -1645$ ft. lbs. Yet the author in the same table gives $M_{G7} = -1490$ ft. lbs.

In the same way at node B, we must have $M_{B11} + M_{B2} = M_{B12}$ but $M_{B11} + M_{B2} = -2710 + 70 = -2640$ ft. lbs. and M_{B12} is given by the author equal to -2893 ft. lbs.

I have calculated the dead load moments in the same system by the exact method outlined above and the table below gives the results together with the author's figures for comparison.

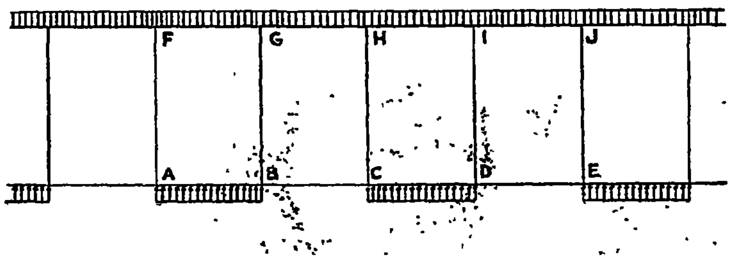
DEAD LOAD MOMENTS.

At	By the elastic theory.	As calculated by the author.
A_1	nil	nil
F_1	nil	nil
B_2	+394 ft. lbs.	+70 ft. lbs.
G_2	−285 „	−85 „
C_3	+110 „	nil
H_3	−156 „	nil
F_6	nil	nil
G_6	−967 ft. lbs.	−1560 ft. lbs.
G_7	−1252 „	−1490 „
H_7	−1031 „	−1040 „
A_{11}	−2570 „	−3130 „
B_{11}	−3497 „	−2710 „
B_{12}	−3103 „	−2893 „
C_{12}	−2941 „	−2850 „

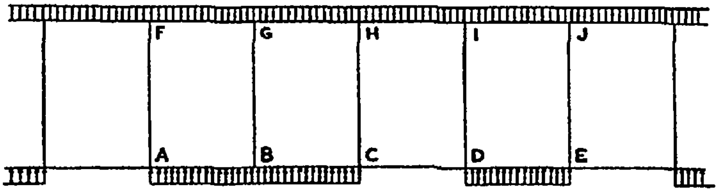
It will be seen that the exact moments in the vertical members are, in cases, almost 4 to 5 times greater than those obtained by the author; in the horizontal members of the frame, there are differences up to 30 per cent between the author's moments and the exact figures. Admittedly the moments are, in any case, small in this bridge and the errors mentioned above may not affect the strength of the structure since the final sections adopted are determined from practical considerations and are stronger than the calculations would require. For greater spans, however, the author's method of fixed point would appear unsatisfactory.

In connection with these dead load moments, another important point has not been considered by the author. The upward reactions of the earth under the bottom horizontal member of the frame have been taken as uniformly and equally distributed right through all the bays. Should one or more bays scour out, the upward reactions in these scoured bays will be nil while in the adjacent non-scoured bays the earth reactions will be increased. In this case the worst conditions of loading for maximum positive span moments and for maximum negative support moments will be somewhat as shown on the sketches below:

Condition of loading for maximum positive span moments:



Condition of loading for maximum negative support moment at B.



For these cases of loading the bending moments in all members, particularly in the bottom horizontal and the vertical members of the frame structure will be found up to 100 per cent higher than the values for which the author has actually designed.

The procedure for calculating the live load moments is not fully detailed in the paper but as presumably the same method of fixed points has been used, the same remarks as for the dead load would apply in this case also. The loading being applied on single bays at a time, the approximation of the fixed point method will be found in this case to be much worse. The distribution of the earth reactions under the bottom horizontal member appears also to be entirely indeterminate for such loading cases and it would be interesting to know the author's views on this point.

For the calculation of temperature and braking effects, the author's formulae are not explained in the paper. In these effects, the only cause of deformation of the frame is a horizontal translation of the joints which is contrary to the second assumption made by the author on page 97 of the paper, and I cannot see how it is possible in these cases to calculate or use any fixed points in the vertical members. The temperature moments of the frame calculated by the method evolved from the Elastic Theory are found almost sixty per cent of the values given by the author.

On page 121 of the paper, the author gives the formula

$$P_1 = Q(\mu_1 \pm \tan\alpha) \pm G \tan\alpha$$

as expressing the braking force. This statement appears incorrect. The formula as used by the author gives the tangential reaction of the vehicle wheels along the decking while the vehicle is running and not when the brakes are applied. When the vehicle is moving, the friction between its rolling wheels and the road surface is very small and the coefficient of friction $\mu_1 = \frac{1}{50}$ given by the author would appear to be acceptable. When the brakes are applied, however, the vehicle wheels are not rolling any more but they are skidding on the road surface. In this case, the friction coefficient between the tyres and the road surface increases more than ten times and the tangential reaction increases proportionately. Adopting a friction coefficient $\mu = 0.25$ for the latter case, the braking force would be

$$P_1 = Q\mu_1 = 4 \times 6 \times 0.25 = 6 \text{ tons}$$

against 1.28 tons adopted by the author. I may mention that the

Indian Roads Congress Code specifies, for the same case, a horizontal force of

$$5 \times \frac{110}{40} = 13.75 \text{ tons.}$$

It is a fortunate coincidence in this case that the column moments due to temperature effects have been over-estimated by the author since he appears to have under-estimated the moments in these columns arising from the dead and live loads and the braking force. With these two errors counteracting each other, the combined final moments for the cases of loading considered by the author may not be far wrong, but it is certainly difficult to say what is the actual factor of safety of the design.

In concluding these remarks, I should like to mention that in the technical literature, one can find several approximate methods for calculating frame structures but very seldom do the authors state clearly how far the results of the methods of calculation they put forward, agree with the correct results of the Elastic Theory. It appears to me essential for every Designer to bear in mind that, in most cases, while the approximation of one method may be satisfactory for a certain form of structure and conditions of loading, the approximation may be too bad to be acceptable for other forms of structure or conditions of loading.

NOTE:—It is regretted that replies to the above comments could not be obtained from the author.

Secretary, Indian Roads Congress.

PAPER No. H—40.

THE USE OF SOIL STABILIZATION IN THE METALLED AND UNMETALLED ROADS IN INDIA—II

By

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The object of this paper is to place before the Indian Roads Congress, the results of the writer's further efforts to make the use of Soil Stabilization an economic success in the country; this paper being a continuation of the one bearing the same title and read by him at the Calcutta Session in February, 1939.

The experiments embodied in the paper referred to above, led to the following conclusions:—

(a) The use of common salt, for the purpose of retaining moisture in a stabilized road crust, becomes fruitless in the dry summer months in the plains of the Punjab, as the humidity remains very low for long periods.

(Common salt was tried in preference to calcium chloride, because of the possibility of getting impure salt duty-free at a very cheap price at the quarry, and of railing it down at concession rates.)

(b) Although a stabilized soil, after it has been compacted by means of a sheeps-foot roller at optimum moisture, is able to withstand the static load of a bullock cart or a heavy truck, it is unable to resist surface abrasion for any length of time, unless some granular material is incorporated into it.

Keeping the above two conclusions in view, the following experiments were tried out:—

EXPERIMENT I.

Stabilization of the Unmetalled link road to Kot Lakhpat Railway Station, from mile 8 of Lahore-Ferozepur Road.

This link road is a portion of the District Board road leading to Raewind, and in addition to heavy goods traffic from Kot Lakhpat Railway Station, it carries a fair amount of mixed through traffic. This link is also used by adjoining brick and lime kilns.

The density of traffic on this link varies from time to time, depending on the receipt of building materials etc. at the Railway Station and the

* First paper on the same subject by the same author has been published in the Proceedings of the Indian Roads Congress, Vol. V (1939).

various crops. Following are the results of traffic census taken at 3 different times:—

(a) A 48-hour traffic census from May, 24, 1939 to May, 26, 1939:—

	Average weight in tons.	Number per 24 hours.
Bullock carts.	2	262
Heavy Motor Trucks	5	132
Motor Cars	1·5	29
Tongas	0·25	83
Pack animals	0·1	231

Total tonnage per 24 hours = about 1300 tons.

(b) A 72-hour traffic census, from March, 5, 1940 to March, 8, 1940:—

	Average weight-tons.	Number per 24 hours.
Bullock carts	2	117
Heavy Motor Trucks	5	37
Motor Cars	1·5	3
Tongas	0·25	53
Pack animals	0·10	149

Total tonnage per 24 hours = about 460 tons.

(c) A 72-hour traffic census from October, 3, 1940 to October, 6, 1940:—

	Average weight-tons.	Number per 24 hours.
Bullock carts, empty	0·5	86
Bullock carts loaded	3·0	111
Heavy trucks empty	2·0	63
Heavy trucks loaded	8·0	79
Horse Vehicles	0·5	94
Lorries loaded	3·0	12
Cars	1·5	16
Pack animals	0·10	330

Total tonnage per 24 hours = about 1270 tons.

The bullock carts used on this road are mostly wooden tyres, but very heavily loaded; they carry 50 cement bags at a time. The trucks used are mostly of 5 tons carrying capacity.

The soil on the link road was mostly fine silt, so that it offered very little resistance to traffic loads, both in the dry and the wet weather, with the result that the road remained in a very bad condition all through the year. Photographs figures 1 and 2 show the state of the road in different weathers.

Weather Conditions:—The general weather conditions in the area in which this road lies are, torrential rains between long spells of dry weather ; very hot in summer and very cold in winter ; humidity generally low. The area is liable to flooding during rains. The centre 9 feet width of road crust was designed to the following specification :—

Foundation:—5 inches of loose graded soil, to be compacted at optimum moisture, by means of a sheeps-foot roller, and finished with a 5-ton petrol roller.

Wearing Course:—5 inches loose of a mixture of graded soil and graded granular material, to be compacted at optimum moisture by means of a 5-ton petrol roller.

A width of 3 feet on each side of the central portion was designed to the following specifications:—

Foundation:—The existing soil to be watered and rolled with a light roller.

Wearing Course:—5 inches of loose graded soil to be compacted at optimum moisture with a sheeps-foot roller and the top 2 inches to be impregnated with graded granular material.

The total formation width of the road to be kept 20 feet, there being a 2½ feet wide unstabilized shoulder on each side.

The designed section of the road is given in figure 3.

Field Work:—The soil on the road being deficient both in clay and in sand, a search was made in the near vicinity of the road for these two materials. Sand was obtained from the bed of a canal distributary 2 miles away. Two samples of clayey soil were selected for examination, one from a clay deposit about half a mile away and another on the road-side buried about a foot under-ground.

Samples of the existing soil on the road were taken wherever the soil seemed to change. This was done both by sight and by making careful enquiries from people who had seen the behaviour of the road under varying weather conditions. Three samples in all were taken.

Laboratory Work:—The samples of soil were subjected to the following laboratory tests :—

(*a*) Mechanical Sieve Analysis, to find out the sand content of the soil and also the percentage of a mixture of silt and clay.

(*b*) Plasticity Index, to find the extent of effective clay in the soil.

The sand was subjected to sieve analysis alone to find out its silt content.

The trial soil mixtures were also subjected to tests (*a*) and (*b*) above and the mixtures finally adopted for use were subjected to the optimum moisture test.

All the above tests have been described already in my paper referred to in the beginning, and it is therefore considered unnecessary to repeat them here.

The laboratory analyses of the various samples and mixtures, yielded the following results :—

(a) *Road Soil Section 1.—*

Retained on No. 10 sieve	= 1·00 per cent.
Passing No. 10, but retained on No. 40.	= 5·50 per cent.
Passing No. 40, but retained on No. 200	= 30·50 per cent.
Passing No. 200	= 63·00 per cent.
Plastic limit	= 19·25
Liquid limit	= 26·80
Plasticity Index 26·80 minus 19·25	= 7·55

(b) *Road Soil Section 2.—*

Retained on No. 10 sieve	= 0·00 per cent.
Passing No. 10 but retained on No. 40	= 2·00 per cent.
Passing No. 40 but retained on No. 200	= 25·20 per cent.
Passing No. 200	= 72·80 per cent.
Plastic limit	= 13·5
Liquid limit	= 23·2
Plasticity Index 23·2 minus 13·5	= 9·7

(c) *Road Soil Section 3.—*

Retained on No. 10 sieve	= 9·30 per cent.
Passing No. 10, but retained on No. 40	= 8·10 per cent.
Passing No. 40, but retained on No. 200	= 25·50 per cent.
Passing No. 200	= 57·10 per cent.
Plastic limit	= 15·7
Liquid limit	= 23·9
Plasticity Index 23·9 minus 15·7	= 8·2

(d) *Sample of clayey Soil half a mile away from road.—*

Retained on No. 10 sieve	= 0·00 per cent.
Retained on No. 40 sieve	= 0·00 per cent.
Retained on No. 200 sieve	= 14·80 per cent.
Passing through No. 200 sieve	= 85·20 per cent.
Plastic limit	= 15·2
Liquid Limit	= 28·3
Plasticity Index	= 13·6

(e) *Sample of clayey Soil on the road-side:—*

Retained on No. 10 sieve	= 0·00 per cent.
Retained on No. 40 sieve	= 0·00 per cent.

Retained on No. 200 sieve	= 11·20 per cent.
Passing No. 200 sieve	= 88·80 per cent.
Plastic Limit	= 19·2
Liquid Limit	= 43·5
Plasticity Index	= 24·3

This soil was selected for admixture due to its high plasticity Index.

(*f*) *Sample of sand from the Canal Distributory.*—

Retained on No. 10 sieve	= 0·00 per cent.
Retained on No. 40 sieve	= 15·00 per cent.
Retained on No. 200 sieve	= 69·00 per cent.
Passing No. 200 sieve	= 16·00 per cent.

The mixtures ultimately selected were:—

(*i*) FOR THE FOUNDATION COURSE:—

(*a*) *For Section 1.*

Top Soil	= 65 per cent.
Clay	= 10 per cent.
Sand	= 25 per cent.

(*b*) *For Section 2.*

Top Soil	= 75 per cent.
Sand	= 25 per cent.

(*c*) *For Section 3.*

Top Soil	= 65 per cent.
Clay	= 15 per cent.
Sand	= 20 per cent.

(*ii*) FOR THE WEARING COURSE:—

(*a*) *For Section 1.*

Top Soil	= 53 per cent.
Clay	= 22 per cent.
Sand	= 25 per cent.

(*b*) *For Section 2.*

Top Soil	= 50 per cent.
Clay	= 25 per cent.
Sand	= 25 per cent.

(*c*) *For Section 3.*

Top Soil	= 55 per cent.
Clay	= 25 per cent.
Sand	= 20 per cent.

The principle underlying the design of the foundation course has been, to keep the clay content rather on the low side, so that, with the increase in its moisture content during rainy season, there should be no softening of the foundation due to excess of clay.

In the case of the wearing course, however, the clay content of the soil mortar had to be kept comparatively high, so as to allow of its getting sufficiently hard during the dry weather to hold the granular material together and thus to give the wearing course both structural stability and wearing quality. The idea is to have so much clay in the soil mortar, that on getting wet, it will expand sufficiently to fill up all the voids in the crust and thus make it impervious to water.

In Section 2, the mixture was purposely designed with a large excess of clay, the idea being that when the crust gets soft during wet weather due to excess of clay, sand would be mixed into it in controlled quantities till it starts behaving perfectly, and thus the optimum mixture determined.

MATERIALS.

Clay:—The clay with a Plasticity Index of 24·3 was selected. In its dry state, this clay was so hard that it would be very difficult and expensive to dig it out and to break it up. The source of clay was therefore flooded and the water was allowed to stand over it for a couple of weeks. When the water all soaked in to a depth of about 3 feet and the top started to dry off, the moist clay was excavated and broken up at the same time with the backs of the spades, before carrying it to site, where it was further broken with wooden "*thapis*" before stacking.

Sand:—Sand was taken from the bed of a canal distributary about 2 miles away. It was actually the material obtained from silt clearance, and in order to make sure that the sand carried to site did not contain too much silt, several rough sieve tests with a No. 200 sieve were taken by the subordinate in-charge at the various heaps.

Granular Material:—(*a*) Crushed Bricks: Well burnt brick was crushed by hand in an attempt to grade it from ¾ inch downwards. The hand breaking left about 25 per cent stuff over 1 inch size. This was screened out and recrushed under a 10-ton roller, by sprinkling it on a tarred surface, *vide* figure 4.

The grading of crushed brick as ultimately obtained was :—

	By weight
Retained on 1" screen	= 2·2 per cent.
Passing 1" screen but retained on ¾" screen	= 22·5 per cent.
Passing ¾" screen but retained on ⅜" screen	= 47·1 per cent.
Passing ⅜" screen but retained on ¼" screen	= 15·0 per cent.
Passing ¼" screen but retained on ⅛" screen	= 12·1 per cent.
Passing ⅛" screen	= 1·7 per cent.

The grading aimed at was :—	*By weight*
Retained on 1" screen	= 0 per cent.
Retained on $\frac{3}{4}$" screen	=15 per cent.
Passing $\frac{3}{4}$" but retained on $\frac{3}{8}$" screen	=30 per cent.
Passing $\frac{3}{8}$" but retained on $\frac{1}{4}$" screen	=25 per cent.
Passing $\frac{1}{4}$" but retained on $\frac{1}{8}$" screen	=20 per cent.
Passing $\frac{1}{8}$" screen	=10 per cent.

(*b*) Crushed Kankar. The locally available variety of *kankar viz.* the *pea-kankar* was used and the following grading was obtained by beating it down with " *lathis* "

	By weight
Retained on 1" screen	= 2·7 per cent.
Passing 1" screen but retained on $\frac{3}{4}$" screen	=13·5 per cent.
Passing $\frac{3}{4}$" screen but retained on $\frac{3}{8}$" screen	= 42·5 per cent.
Passing $\frac{3}{8}$" screen but retained on $\frac{1}{4}$" screen	= 18·2 per cent.
Passing $\frac{1}{4}$" screen but retained on $\frac{1}{8}$" screen	=15·1 per cent.
Passing $\frac{1}{8}$" screen.	= 8·3 per cent.

The grading aimed at was the same as in the case of crushed brick.

The grading obtained is not very satisfactory and hand crushing is also very expensive. It is proposed to try out portable mechanical crushers.

PROCEDURE.

Earth Filling:—Except in a length of about one furlong where there was upto 3 feet of bank, the filling was not over 6 inches. In the portion with high bank, the filling was done with moist soil in layers of 6 inches and the coolies carrying the fill soil were made to walk on the bank so as to go on consolidating it.

Preparation of Foundations:—The foundation was watered and rolled and prepared to a camber of 1 in 40, figure 5.

Foundation Course:—The top soil, sand and clay were mixed dry outside and spread on the road (central 9 feet only) in the required thickness of 5 inches loose, after the rest of the formation had been filled up with 5 inches loose top soil, watered and rolled, figure 6.

The optimum moisture was then added to the mixture, by dividing the evenly dressed loose dry mixture, into suitable sized "*kiaris*" or partitions, so that each "*kiari*" would take one or two *mashak*-fulls of water. The water, thus added in the evening was allowed to stand over-night, and in the early morning when it had dispersed itself through the depth of

the soil, it was mixed again by spades and dressed. The moist soil was then rolled with a sheeps-foot roller, drawn by a pair of bullocks, figure 7, and finally finished off with a 5-ton roller.

Wearing Course—Berms and Centre Portion :— The 2½ feet wide shoulder on each side was first filled up with top soil, watered and rolled. Then a width of 3 feet on the inside of each shoulder was filled to a depth of 5 inches with the soil mixture for the berm, mixed dry. The central portion was then filled in with a dry mixture of top soil, sand, clay and crushed brick (or *kankar*) to a depth of 5 inches, figure 8. Out of the crushed brick (or *kankar*) however, about 10 per cent of the total quantity was kept aside for use on the surface. This was generally small size stuff.

The central portion and the berm were then divided into convenient sized partitions, each of which would require a whole number of *mashaks* for its optimum moisture, *vide* figures 9(*a*) and 9(*b*). The water was allowed to soak through over-night, and the mixtures turned over with spades in the morning.

The 3 feet wide berm on each side was then compacted with sheeps-foot rammers *vide* figure 10, till the feet of the rammers would not penetrate more than 1½ inches into the soil mixture. The requisite quantity of crushed brick (or *kankar*) was then spread over the loose soil, and mixed up with it, by means of rakes.

The whole formation width of 20 feet was then rolled once with a 5-ton roller. After this a mixture of the small sized stuff saved from the granular material, and fine clay in equal proportions was spread over the 15 feet width in a moist state. The rolling was then completed.

Rolling:—The roller was run at an angle of about 45 degrees all the time (figure 11) so as to avoid any possibility of cross corrugations which can easily form in a construction of this type and help to cause dis-integration of the pavement.

Curing:—The finished surface was sprinkled over with water twice a day for a week, so as to prevent damage by the roller or any other constructional traffic passing over it in its early stages of incomplete compaction.

Final compaction under traffic:—On completion, the whole road was given a thick sprinkling of water and next day when the surface looked moist, but not wet, it was thrown open to traffic.

For a period of six weeks, a sprinkling of water was given to the road every day towards the evening. This completed the final compaction of the road under traffic—the last but the most important stage in the construction of soil roads.

Cost of Construction:—The statement in figure 12 is a copy of the revised estimate for the work, giving the cost as originally estimated for and as actually incurred.

Maintenance:—The road was opened to traffic in the end of December 1939.

A thick sprinkling of water was given to the road once a month upto April 1940.

Section 2, where an excess of clay had been deliberately used, got softened after each rain and developed ruts. Sand was spread over it in the hope of getting the traffic to mix it up. But the traffic tended to go in the ruts and hence no mixing took place, except where the ruts were.

In a further effort to mix the sand properly, the area was flooded with water and a bullock cart was made to go up and down all over the width for a day. This did do the mixing to an extent but it was still left patchy, with the result that some localised spots kept behaving badly, the behaviour of the rest of the surface not being very uniform either. This was borne out by a laboratory analysis of soil at various points, which showed widely varying results. This method of mixing has been a failure, and so has been this section. It is now proposed to try sand mixing under a multi-wheeled bullock roller, but it cannot be said whether it will be successful.

In April 1940, when the Soil Research Sub-Committee of the Indian Roads Congress (figure 13*a*), inspected the experiment the condition of the three sections was as follows :—

Section 1 :—

Very slightly dusty, otherwise in excellent condition. No ruts at all. No signs whatever of the brick aggregate dislodging any where, or crushing in the body of the crust. Very slight wearing of crushed brick on the top due to surface abrasion under the bullock cart wheel, resulting in a thin layer of about 1/8 inch size brick aggregate on the surface, which, mixed with the soil, actually acts as a protective coat against further abrasion.

Section 2 :—

The Section was patchy and could be called a failure.

Section 3 :—

The general condition of the section was good, though it was more dusty than Section (1), and there was more wearing of *kankar* on the surface than in that section. This was naturally to be expected as the *kankar* locally available was softer than crushed brick.

The Soil Research Sub-Committee, entered the following remarks in the minutes of their meeting held at Lahore, soon after they inspected the site :—

> "The Committee also inspected some experiments carried out by the Punjab Government on the link to the Kot Lakhpat Railway Station. These experiments were carried out 3½ months ago. They are on an all-earth road carrying heavy traffic for such construction and except for the length where an extra percentage of clay was deliberately used (Section 2), are to-date standing well. It is felt that this road will give good service, but the cost of maintenance may be high and, therefore, a careful record should be kept of expenditure."

After April, the monthly watering of the road was stopped, in order to see how long the road will last before requiring another watering. The condition remained good during May and June, and excellent during the Monsoons. There were atleast three torrential rains (as much as about 3 inches overnight) but without causing rutting or any damage whatever in Sections 1 and 3.

Towards the middle of November, the road has become rather dusty on the surface, though the granular material is still firmly embedded in the soil mortar and it is felt that a watering is now needed. It rained last on September, 29, 1940. Figures 13 (*a*), (*b*), and (*c*) show the state of the road at various stages.

Cost of maintenance :—So far, the cost of maintenance has been low. But as it would not be a fair estimate of it, till the present dry spell has passed, it is proposed to give the figures at the time of the congress session.*

Economic Possibilities :—The total cost of one mile length of the road, with a usable width of 15 feet, is Rs. 3212/-. Out of this, Rs. 401/- *i. e.* the cost of earth-work in filling, and of the culvert should not be considered for purposes of comparison, as these would be common items for any type of construction. The net cost would, therefore, be about Rs. 2800/- *i. e.* Rs. 2000/- for the centre 9 feet, and Rs. 800/- for the two berms, 6 feet wide in all.

(In normal circumstances, the cost would drop another Rs. 500/- as the price of sand in any other locality would not be so high, the cost of mixing and watering would come down as the labour gets used to the work and the road inspector would not be required for more than one month for every mile of road constructed).

The density of traffic on this section is even higher than in miles 10 and 11 of the arterial road from Lahore to Ferozepur (Experiment III) and actually justifies the construction of a proper metalled road, the cost of which at this locality for a 4½ inches soling coat and 4½ inches metalling, would be Rs. 7700/- for 9 feet width and Rs. 12800/- for 15 feet width.

It is possible to surface treat this stabilized pavement, after applying a suitable tack coat.

This particular experiment by itself, however, only shows the best that a stabilized soil road can do. Ordinarily on an unmetalled road, the traffic would be much lighter and, therefore, will require a lighter and consequently cheaper pavement.

The main object behind the experiment was to remove the wrong but deep impression, from the minds of the road engineers in this country, that no stabilized soil can withstand bullock cart traffic.

But if we were to stretch the principle further, it is not difficult to visualize, that whereas heretofore, a road had to stay as a natural soil pavement, usable in fair weather only, until the density of traffic and the

* The figures are reproduced in the statement appended at the end.

availability of funds justified the putting up of an expensive metalled road, now there is a possible series of pavements between these two extremes, which can provide roads at varying costs, to suit different traffic conditions and above all, usable in all kinds of weather.

This straightaway makes it possible for district boards etc. to increase their milage of "all weather" roads, and thus to help in the "opening up" of the country, which is one of the most essential features of rural development.

EXPERIMENT II.

Stabilization of soil in mile 42 of Hoshiarpur-Dharamsala Road.

This is an important trade route, and the road is being gradually metalled.

Mile 42 of this road lies between two "*chows*" (hill torrents) in the sub-mountainous Hoshiarpur District. The soil in mile 42 is predominantly fine sand, with a little coarse sand and silt, and has no binder to speak of.

This mile used to develop deep ruts very quickly in the dry weather.

Traffic:—The traffic on this road is mixed bullock cart and lorry traffic, and totals about 122 tons a day; most of the carts have iron tyres.

Weather Condition:—The general weather conditions of this area are rather wet, the rains being both torrential and of long duration. The average yearly rainfall is 40·22 inches. There are also, however, atleast a couple of longish dry spells and many short dry spells, during all of which, this mile behaved very badly.

Foundation:—When the original soil survey was done, the foundation was found to be fairly compact, as clay had apparently been thrown on the road from time to time and had got mixed up with the sand under traffic. But the local authorities later on decided to raise the road and used different soils for doing so.

The treatment carried out for making the filling fit to act as a foundation, is given in the following excerpt from a letter addressed by the writer to the Executive Engineer in-charge of the road:—

> " I found however, that a certain amount of filling has been done, by you, over which it is intended to put the stabilized crust. As this filling is different in composition from the original bed which contained both coarse material and a slight quantity of clay, it must receive a treatment before it can safely act as a foundation.
>
> The filling is of two kinds. One is almost pure sand and the other is a soil very rich in clay.
>
> The treatment to be done on the sand filling is as follows :
>
> A layer of the same quality of clay which is being collected for the top crust should be spread on the dry sand filling in a thickness of 3/4 inch and the traffic

allowed to run freely over it to mix it up. After a few days another similar layer should be spread and allowed to get mixed up under traffic, taking care that deep ruts are filled up from time to time by dragging about the filling.

When this process is completed, water at the rate of about 1/3rd gallon per square foot should be spread over the portion preferably towards the evening and the portion rolled with a light roller next morning. The traffic will then do the final compaction.

The treatment to be done on the clay filling is exactly the same, except that sand layers will be substituted for clay, and the clay filling will be thoroughly sprinkled with water to soften it down to a depth of about 3 inches, before the sand is spread. Mixing will be done by traffic.

There will be no rolling necessary in this case. The traffic will do all that is wanted."

The above was done by the ordinary maintenance gangs, in the course of their normal work.

Field Work :—The top soil at the site is very deficient in binder and slightly so in filler. A clay deposit was found about 4 furlongs away from the site, but it was not possible to get any silt within economic distance. The top soil throughout the length in which the experiment was carried out was the same.

Laboratory Work :—The following is the laboratory analysis of the top soil and the clay admixture :—

Top soil.

Retained on No. 10 sieve	= 0·00 per cent.
Passing No. 10 sieve but retained on No. 40 sieve	= 9·10 per cent.
Passing No. 40 sieve but retained on No. 200 sieve	= 83·60 per cent.
Passing No. 200 sieve	= 7·20 per cent.
Plastic Limit	Non plastic.
Liquid Limit	
Plasticity Index	

Coarse sand.

Retained on No. 10 sieve	= 0·00 per cent.
Passing No. 10 sieve but retained on No. 40 sieve	= 63·90 per cent.
Passing No. 40 sieve but retained on No. 200 sieve	= 31·70 per cent.
Passing No. 200 sieve	= 4·10 per cent.

Clayey Soil.

Retained on No. 10 sieve	= 0·00 per cent.
Passing No. 10 sieve but retained on No. 40 sieve	= 0·00 per cent.
Passing No. 40 sieve but retained on No. 200 sieve	= 19·20 per cent.
Passing No. 200 sieve	= 80·80 per cent.
Plastic Limit	= 13·3
Liquid Limit	= 41·9
Plasticity Index	= 28·6

The coarse sand was really not necessary but as it was collected through a misunderstanding, it was allowed to be used.

The mixture ultimately selected was :—

Top Soil	=33·3 per cent
Coarse sand	=33·3 per cent.
Clayey Soil	=33·3 per cent.

The principle on which the above mixture was designed, was to keep the clay content lower than in the wearing course in Experiment I (though a small extra quantity of clay was allowed to make up for the deficiency of silt, so as to get the density required). This was done both because the locality is more wet than that of Experiment I and as it was intended to surface treat the length after the end of the rainy season, during which necessary compaction under traffic would have taken place.

Materials :—Clay was dug out of the deposit referred to before, after rendering it soft with water, and was broken up in its moist state, before carriage to site.

Sand was collected from the bed of the "Swan".

Granular material in the shape of rounded pebbles was also collected by screening, from the bed of the "Swan." It had the following grading:—

Berms :—	*By weight*
Retained on 1" screen	= 5·1 per cent.
Passing 1" screen but retained on ¾" screen	=21·3 per cent.
Passing ¾" screen but retained on ⅜" screen	=37·9 per cent
Passing ⅜" screen but retained on ¼" screen	= 23·1 per cent.
Passing ¼" screen but retained on ⅛" screen	= 9·2 per cent.
Passing ⅛" screen	= 3·2 per cent.

PROCEDURE

Preparation of bed :—The bed was scraped to a camber of 1 in 40 and rolled with a 1-ton roller after giving it a thick sprinkling of water. This was timed to immediately precede the spreading of top course material so as to save having to wet the bed once again.

Wearing Course :—Sand, clay and top soil were first mixed dry and then the granular material was added and the whole thing mixed again. The dry mixture was then placed in stacks about 20 feet by 20 feet by 1½ feet, and after levelling off the top carefully and making bunds of the same material at the top, the requisite quantity of water for optimum moisture was allowed to stand over it.

This operation was finished towards each evening and the water was allowed to soak through during the night.

Next morning, all that was necessary was to remove about 4 inches of dry material from all round the stack, and to carry the rest straight to the road for spreading on the wet bed. The small mixing needed was done by the man who was cutting the material from the stack and pouring it into mortar pans, for being carried to the road. The dry material was separately mixed with water and used up.

This method of mixing was found to be cheaper, quicker and more practical than the method used in Experiment I. The mixing was also found to be better.

After dressing, a sprinkling of moist clay and fine bajri mixed in equal quantities was given over the surface at the rate of 1 cubic foot material for 88 square feet. This quantity of bajri was saved from the wearing course material.

The rolling was then done with an 8-ton roller, which was the lightest power roller available in the locality. This roller was found to be too heavy for the mixture and so it was only lightly rolled and finished off with a 1-ton roller. Cross rolling was done as far as possible to avoid longitudinal corrugations.

Curing:—Curing was done by watering twice a day for 4 days, when traffic was let on.

The reason for watering twice a day for 4 days only in this case, instead of once a day for seven days, as in Experiment 1 was, that the initial rolling was imperfect and no drying of the crust was desirable.

The compaction under traffic was carried out for 22 days by giving a thick sprinkling once a day.

As water was very expensive, and the rains were coming on, the rest of the compaction was left to be automatically done by traffic during rains.

Cost of construction:—Cost for 12 feet mile.			Rs.
Imported clay—6125 cft.	@ 20/- per thousand.	=	123/-
Top soil 5280 cft.	@ 3/- per thousand.	=	16/-
Sand 2300 cft.	@ 5/- per cent.	=	115/-
Sand 2980 cft.	@ 3/- per cent.	=	89/-
Bajri 3/4" to 1/8", 5280 cft.	@ 10/- per cent.	=	528/-
Labour for mixing, watering, laying and rolling		=	350/-
Extra cost of importing water		=	168/-
Preparation of foundation		=	60/-
			Rs. 1449/-

Say	..	..	= 1450/-
Cost for 9 feet mile	..	..	= 1087/-
Say	..	..	= 1100/-

Behaviour :—The road was done in May last and has behaved very well so far. All the possible compaction is considered to have already taken place under traffic during the summer rains, and the road is now fit to take surface treatment, arrangements for which are already in hand.

EXPERIMENT III.

Stabilization of the unmetalled berms in Miles 10 and 11 of the Lahore-Ferozepur-Ludhiana Arterial Road No. 5 (metalled).

This road is well known for the thick clouds of dust that are raised by traffic during the dry season and the slush and slipperiness of the berms in wet weather. Miles 10 and 11, were the worst miles in this respect, the soil being cohesionless silt.

Traffic :—The traffic in this mile is 849 tons per 24 hours and includes 159 bullock carts and 377 motor vehicles.

Design :—The foundation of the berms, upto a width of over 5 feet on each side of the metalled edge, is very compact below a depth of about 2 inches. It is a happy mixture of sand, clay and silt and also some granular material flown off from the newly tarred surface, which has got compacted under traffic in good time, under suitable moisture conditions.

It appears that the filling on the road in the first instance was done with good soil, but that during maintenance only the cohesionless silt available as top soil had been used.

As the foundation soil was found to be stable, it was decided to use only 3 inches loose thickness of stabilized soil wearing coat, with 40 per cent *kankar* mixed in it.

The width of treatment was kept 5 feet on each side making a total usable width of 22 feet.

Field Work :—As the top soil was evidently deficient both in clay and sand, a search was made for both these materials in the vicinity. Fine sand was available in the bed of a canal minor flowing along side the road. A good clayey soil was found at a depth of over 2 feet, at site. The belt of clayey soil was about 6 feet in thickness.

Laboratory Work :—The laboratory analysis of the berm soil, the clayey soil and the sand was as follows :—

Berm soil :—

Retained on No. 10 sieve	= 10·30 per cent.
Passing No. 10 sieve, but retained on No. 40 sieve	= 5·10 per cent.

Passing No. 40 sieve but retained on No. 200 sieve	=	15·20 per cent.
Passing No. 200 sieve	=	69·10 per cent.
Plastic Limit		Non plastic
Liquid Limit		
Plasticity Index		

Clayey Soil :—

Retained on No. 10 sieve	=	0·00 per cent.
Passing No. 10 sieve but retained on No. 40 sieve	=	0·00 per cent.
Passing No. 40 sieve but retained on No. 200 sieve	=	27·20 per cent.
Passing No. 200	=	72·80 per cent.
Plastic Limit	=	14·5
Liquid Limit	=	44·2
Plasticity Index	=	29·7

Sand :—

Retained on No. 10 sieve	=	0·00 per cent.
Retained on No. 40 sieve	=	14·10 per cent.
Retained on No. 200 sieve	=	61·30 per cent.
Passing No. 200 sieve	=	24·40 per cent.

The berm soil was considered useless, as it contained very little besides cohesionless silt, and as the clayey soil and sand were available at the door step, the berm soil was excluded from the final soil mixture which consisted of two parts of clayey soil and one part of sand. To this 40 per cent graded *kankar* was added, the grading being the same as in Experiment I.

Execution.—The process of mixing, compaction and curing was the same as for the Kot Lakhpat Road, Experiment I.

There was one awkward difficulty met with on this work. In order to prevent the breaking of the edges of the tarred central portion, they had been sloped off. This necessitated the cutting of the sloping metalled portion over 6 inch on each side, so as to get a proper joint between the metalled and the stabilized pavements. As there was no help for it, this was unwillingly done. In some short lengths, however, the sloped portion being very wide was not cut off entirely and so the stabilized surface had partly to ride over the tarred sloping edge *vide* figures 14 (*a*) and 14 (*b*). This was a mistake as will be seen later.

In a small length, crushed brick was replaced by kankar, the grading of the crushed brick being the same as for Experiment I. This was done to compare the wearing qualities of the two materials.

Behaviour:—The experiment was completed towards the end of December 1939.

In April 1940, the Soil Research Sub-Committee of the Indian Roads Congress, inspected the experiment and the following remarks were entered in the minutes of the meeting held afterwards :—

> "The Committee also inspected some experiments carried out by the Punjab Government in miles 10 and 11 of the Lahore-Ferozepur Road. The work was done some four months ago. It is unfortunate that the experiments are again on the berms of a road, but they are very successful.
>
> The Committee, however considers that the cost was high."

Towards the middle of November, the condition of the berms is excellent, though it is felt that they require to be once sprinkled with water.

The monthly sprinkling of water was stopped in April 1940, to see how long the berms can go on without requiring to be watered.

A length of half a furlong has been left without any monthly water sprinkling from the very beginning, and though it is still in good condition in the middle of November, it is yet too early to draw any conclusions from its behaviour. The idea is to see whether with a very restricted use of chemicals, the berms could be maintained economically in areas where no canal water is available along the road side, for monthly watering. Chemicals will be used on this section when absolutely necessary.

The brick is behaving generally much better than *kankar*, though due to the fact that traffic passes over the berms only for crossing or overtaking, there is hardly any crushing of *kankar* on the top as in the case of Experiment I, where the traffic is heavier and the whole of it has to pass over the stabilized portion.

The wear on the berm in a little over 10 months is hardly $\frac{3}{8}$ inch and at this rate it is expected that the crust will last at least 5 years, if allowed to wear out completely.

At the places where the sloping edge of the metalled portion was not cut out entirely, the portion "A" in figure 14 (*a*), got pushed out by traffic, and the rain water standing in this portion for many hours, caused a comparative softening of the adjoining portion, resulting in squeezing out of the stabilized soil to a depth of about one inch in these portions. Patching had to be done here, and now the portion "A" is being filled up with tar premixed bajri and no further trouble is expected after that has been done. This should have been done in the first instance, as there are only a few such lengths a couple of feet long each, figures 15, 16 and 17, relate to this experiment.

Economic Possibilities:—The cost of stabilization in this case is Rs. 900/- per 10 feet wide mile or Rs. 1·7 per 100 square feet.

The service value of these stabilized berms, in rural areas, compares not unfavourably with actual widening of metalling, in as much as the danger to traffic through dust clouds or slippery slush is entirely

eliminated. The cost of widening the metalling to the same extent would be about Rs. 12,000/- per mile.

Even otherwise, judging from the behaviour of the stabilized berms during the last 10 months, the life of such a berm may safely be taken as 5 years. This will spread the initial outlay to Rs. 180/- per year. The cost of maintenance as based on the experience gained during the last 10 months, may be taken as Rs.70/- per year, *i. e.* ¼th of a cooly per mile, plus Rs. 34/- for patch materials.

The total cost of making and maintaining the stabilized berms would thus come to Rs. 250/- per year, as against Rs. 225/- per year being actually spent by us at present in the Punjab for keeping the berms in their present *kacha* state. (The figure of Rs. 225/- is taken from Chief Engineer Punjab Public Works Department, (Buildings and Roads Branch) Memo No. 425—427—R.S., dated the 3rd July 1940).

And a point worth special mention is, that during the last 10 months, the traffic has produced no local settlements on these berms in the shape of *tiny depressions which are generally found on metalled roads.* 'This points to two very important conclusions :—

(*a*) That the existing crust of the stabilized berms is strong enough to take up the traffic it is subjected to, and that as such, if it is surfaced over, it should behave like a permanent pavement.

(*b*) That if properly designed and executed and surfaced, a stabilized soil pavement, should behave better than a metalled road, in so far as the formation of small depressions is concerned.

The reason for this is, that in a metalled road, the sharp edges of adjoining stones, are in contact and the continuous vibration set up by fast traffic, and also, the direct load causes the sharp corners to be gradually rubbed smooth, resulting in a denser packing of the stones, which is made possible by the numerous voids in a water bound crust, and which in turn causes depressions on the surface.

In the case of a stabilized soil pavement, however, each bit of granular material is protected by a covering of soil, which acts as a shock absorber, and prevents the rounding off of edges. Further, the maximum possible compaction having already occurred at optimum moisture during construction in the case of a stabilized soil pavement, there is no possibility of further packing under traffic and as such, no surface depressions can be formed after the crust has been surfaced over.

As regards the possibility of surfacing over stabilized soil, the experiments are in hand and it is hoped that it will be possible to do so.

EXPERIMENT IV

Elimination of soling in the widening of metalled roads—Miles 11 to 14 Grand Trunk Road, Lahore Gujranwala Section:—

The use of brick for soling with the object of dispersion of load is an absolute waste of money, because a brick soling is capable of no dispersion of load whatever.

The maximum intensity of pressure at the bottom of a soling brick is the same as the intensity at its top, because the area of dispersion of a wheel load through the wearing crust of a usual thickness of 3 inches, is larger than the area of a brick, and the bricks all act individually.

It is sometimes advocated, that the soling bricks are capable of dispersion of load, by virtue of the facts, that there is friction between the brick faces, and that there is also an arching action, due to the camber of the road.

In actual laying of the soling, the joints are never made so tight as to provide any friction; in fact they are so wide, due to the untrue shape of bricks, that they have to be filled up with earth or sand. As regards the arching action, the impression is entirely psychological, as will be apparent if the tension in the mud joints is calculated and so also the side pressure on the earth abutments for an arch having a rise of three inches only for every 10 feet of span.

The only useful function of the brick soling is, that the area of contact of the load as it is transferred to the earth is large, compared with the area of contact of ordinary metalling, and as such, in the case of weak soils, the resulting compression for the same intensity of load would be less with a brick soling. Brick soling is, therefore, warranted only where the sub-grade soil is poor, and in that case too a flat brick soling is preferable to a brick-on-edge soling, because of its wider area of contact.

The case of the unmetalled berms of old metalled roads is, however, different. For many many years, a few feet width of the berms on either side of the metalled edge, has received compaction, under the wheels of passing vehicles, under different moisture conditions. In some reaches, the soil on the berms has, during the course of ordinary maintence, assimilated a happy mixture of sand, silt and clay, and also stray granular material in the shape of crushed *kankar* or bajri. This graded soil, has gradually obtained an extreme degree of compaction from traffic, under suitable moisture conditions, and stays in that condition, because it is always protected from surface abrasion by the loose earth "*pushta*" that the gangs keep putting on the top, to maintain the berms on the level of the metalled edge.

The thickness of this stabilized soil crust varies from 4 inches to 6 inches and the width from 4 to 5 feet. The crust is practically impervious and is stable under the prevailing loads, in varying weather conditions.

Thus it can be safely assumed, that in the reaches described above, the subgrade is not poor and therefore the use of soling is not necessary.

With this point in view, the experiment in question was taken up. Several miles on Lahore-Gujranwala section of the Grand Trunk Road were due for widening, which was sanctioned to be done according to orthodox practice.

For purposes of comparison, however, a length of half a furlong in each of the miles, 11, 12, 13 and 14, was done without any soling and a metalled crust of 3 inches only (unconsolidated) was used.

The following rules were observed for selecting suitable reaches:—

(*a*) The soil is so compact that it cannot be easily dug with a spade in the dry weather.

(*b*) It does not rut in the wet weather.

(*c*) It does not rut in the dry weather.

(*d*) The only action of traffic on it is surface abrasion.

(*e*) It does not get soft and fluffy in winter owing to the presence of detrimental salt.

(Ruts should be carefully distinguished from surface abrasion, in the dry weather. One may sometimes be misled by the bad condition of the loose "*pushta*" by the side of the metalled edge; this "*pushta*" should obviously be removed before examining the soil.)

EXECUTION.

The surface was dressed down to the required level and camber by careful cutting so that no filling would have to be done. The bed was then thoroughly wetted and a one inch layer of graded soil spread on it. Over this was spread 3 inches of stone metal graded from 1½ inches to ¾ inch and water bound with a 10-ton roller, letting the loose graded soil work up into the voids of the stone metal. The metalling was then surfaced over in the usual manner.

Behaviour :—The experiment was completed in August, 1939 and in November, 1940 their condition is excellent.

Economic Possibilities :—It is felt that a lot of saving can be effected in widening the metalled roads, if soling is eliminated in reaches which satisfy the above conditions.

EXPERIMENT V.

The use of stabilized soil as a foundation in miles 8, 9, 10 (part), 11 (part), 27, 28, 29, 31 and 33, of Lahore Ferozepur Road (widening).

In order to reduce the cost of widening, it was decided to use a stabilized soil foundation ($4\frac{1}{2}$ inches loose) under 3 inches (loose) of stone metal.

The laboratory analysis of the soils in various sections is given in table Figure 18.

It was considered that except in mile 8, the existing soil mixture in each of the other miles is suitable for use as a foundation, in combination with 40 per cent graded *kankar*.

For mile 8, the existing soil was mixed with river sand in the ratio 4:1, and to this mixture *kankar* was added in the ratio 3:2.

The process of execution was the same as in Experiment II, and as a light roller was not available, the rolling was done here also with an 8-ton roller.

Since compaction of a foundation course under traffic is not desirable after the wearing course has been laid on, the following procedure was adopted to fully compact the foundation before putting the wearing course on top.

The mixture was lightly rolled with the heavy roller and left overnight with a thick sprinkling of water. Next morning it was rolled again and then left for 3 days, with a light sprinkling each evening. On the fourth day the top course was consolidated and surfaced as in the case of Experiment IV.

The work has been recently done. There were no local settlements whatever during the course of the consolidation of the wearing coat.

Cost:—The cost is Rs. 650/- per 6 feet wide mile for 5 inches loose thickness, as against Rs. 2137/- for brick-on-edge and Rs. 1425/- for flat brick soling, for the same width. The economy is self-evident.

GENERAL CONCLUSION

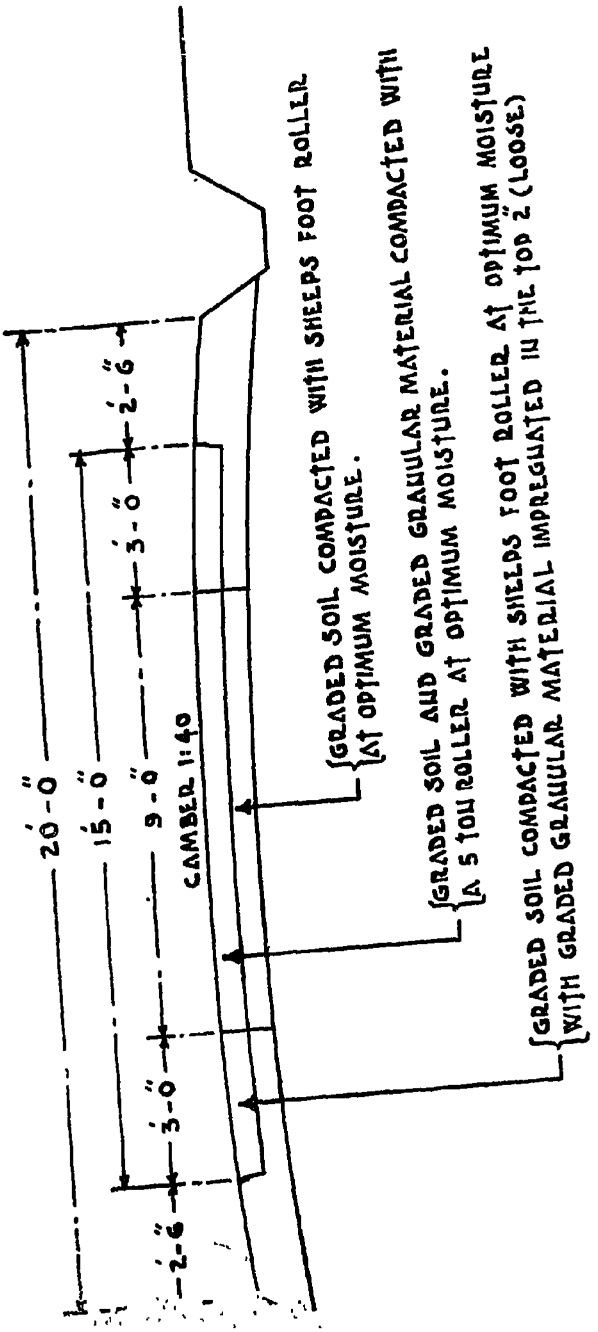
It is strongly felt, that the young science of soil mechanics is not receiving the attention it should, in this country.

The general impression seems to be, that you cannot do anything with soil, so long as the bullock cart is there. It is to be agreed that the bullock cart does make this difficult problem very much more so, but there seems to be no justification for giving it up as a hopeless task, without giving it a fair trial.

Inspite of the many handicaps of research of a quasi-private nature, the results of experiments conducted by the writer for the last 3 years have been very encouraging all along, and it will be a great pity if in view of that, further research is not vigorously carried out. The time has certainly come, when we should get rid of the bias against soil stabilization, and try to give it the place it deserves, in the science of Highway Engineering.

Figure 1
Before Stabilization.
The state of Kot Lakhpat Link Road in the dry weather.

Figure 2.
Before Stabilization.
The state of Kot Lakhpat Link Road after a rain.



SECTION OF KOT LAKHPAT LINK ROAD AS CONSTRUCTED

FIG.—3

Figure 5.
Foundation bed under preparation.
Experiment I.

ng being done on

Figure 7.

Showing Sheeps-Foot Roller pulled by a pair of bullocks, instead of by men as heretofore.

Experiment I.

Figure 8.

Top course. Filling the berms and the central portion.

Experiment I.

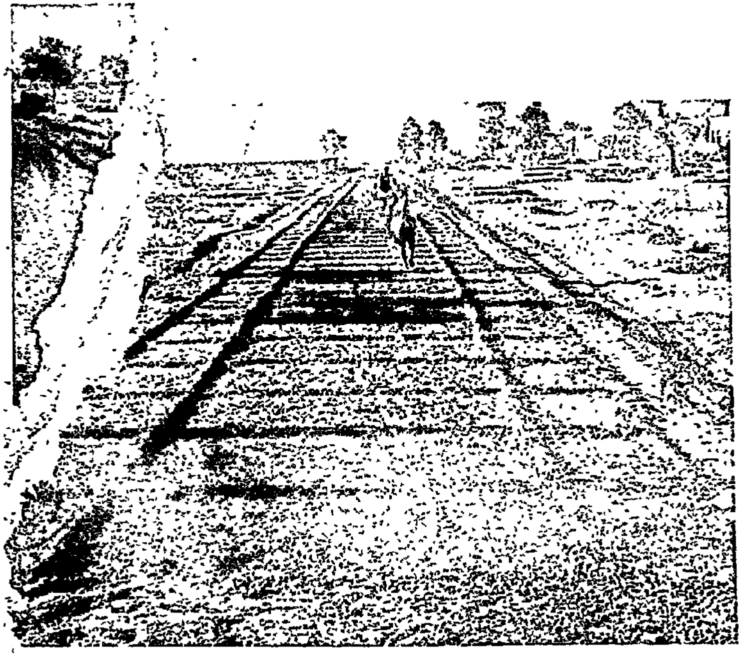


Figure 9 (a).

The road divided into "*Kiaris*" to receive water.
Experiment I.

Figure 9 (b).

The "*Kiaris*" some time after the water has been poured in.
Expeiment 1.

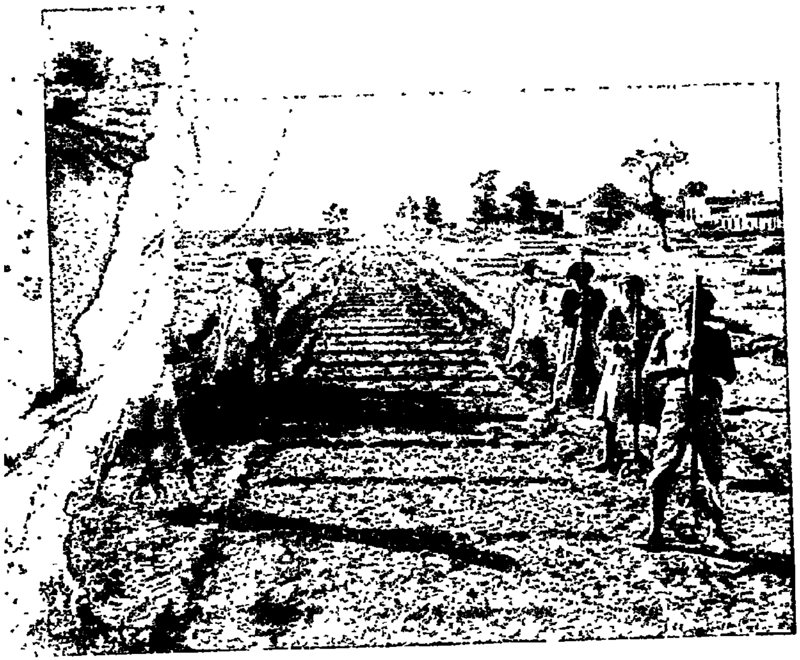


Figure 10.
Showing compaction of berm by Sheeps-Foot Rammers.
Experiment I.

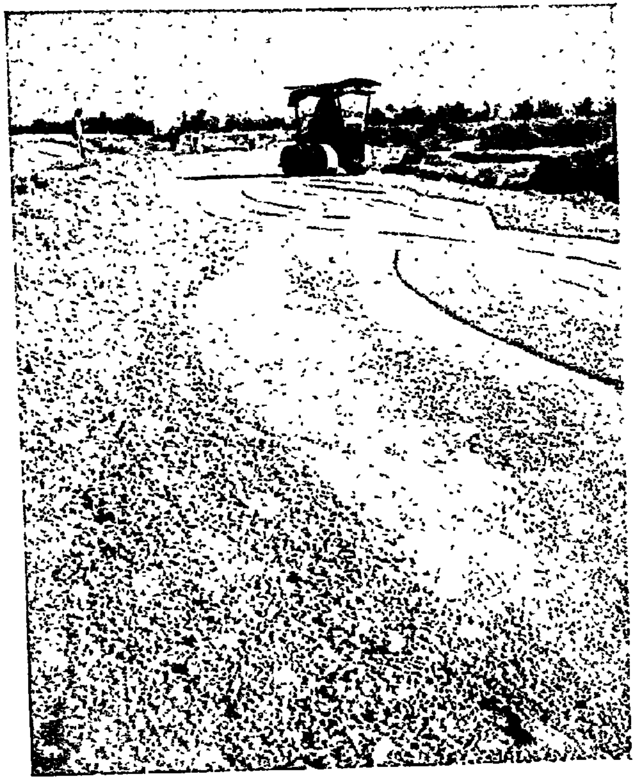


Figure 11.
Showing Cross Rolling of the wearing course.

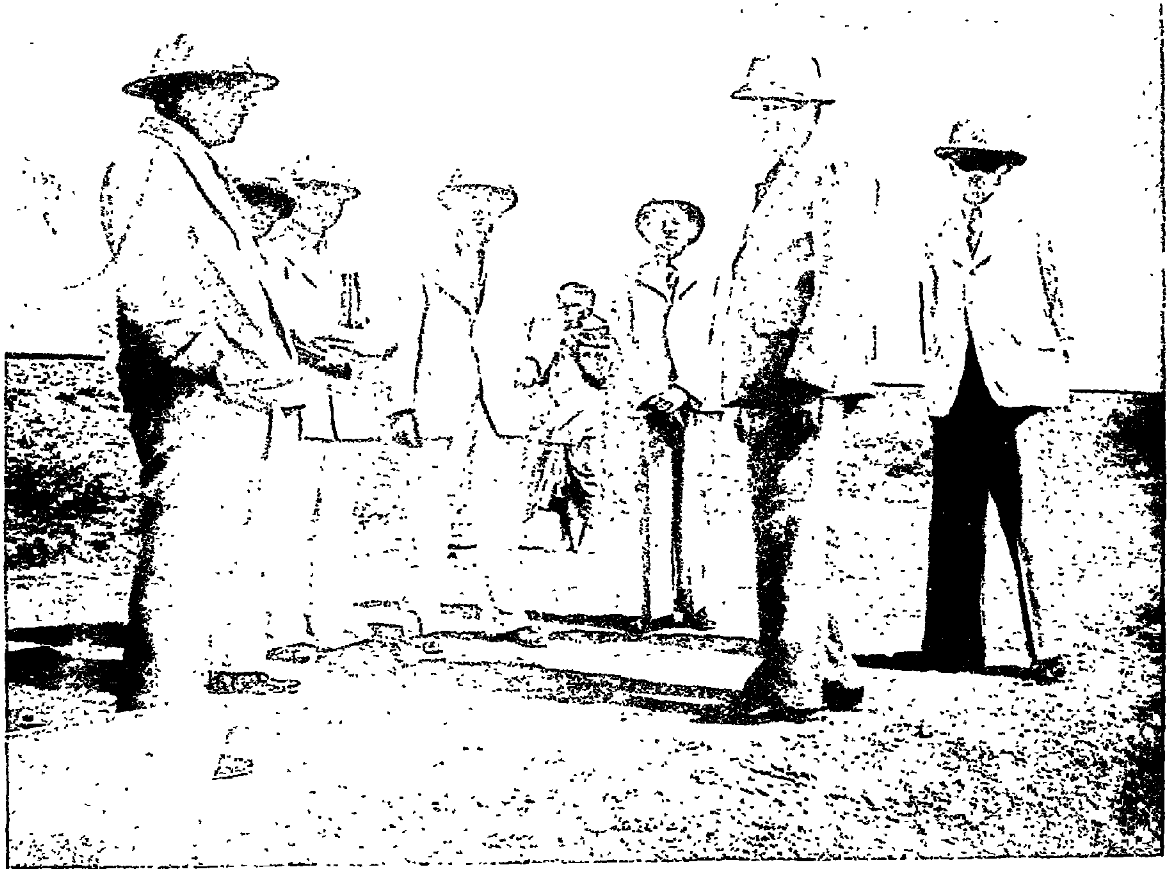


Figure 13 (a).
The Soil Research Sub-Committee of the Indian Roads Congress, inspecting the Kot Lakhpat Link Road in April 1940.

Figure 13 (c).

The state of the Kot Lakhpat Link Road in October 1940.

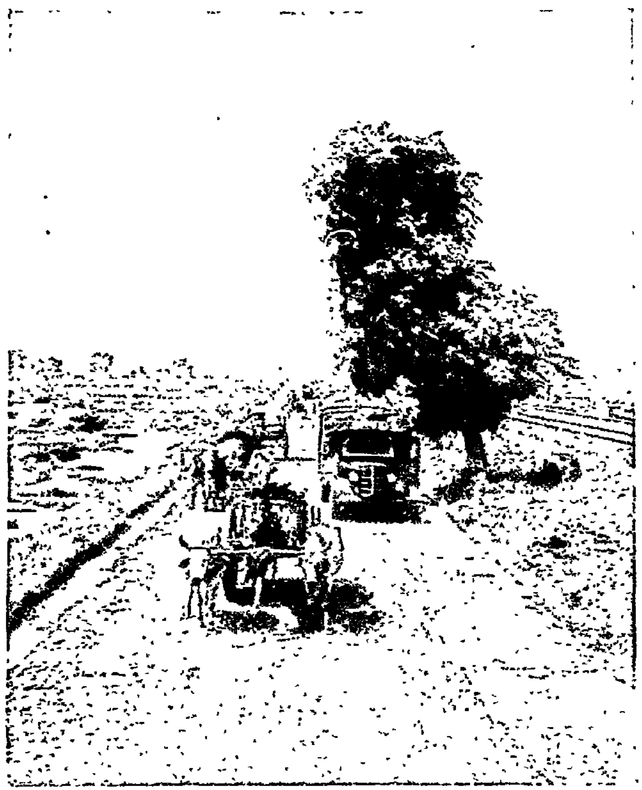


Figure 13 (b).
The state of the Kot Lakhpat Link Road in August 1940.

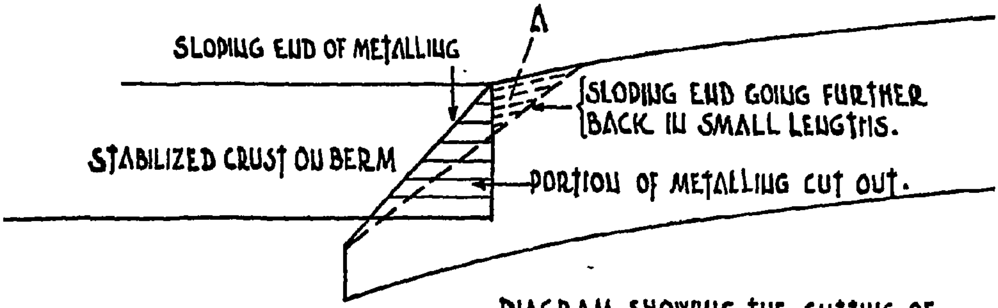


DIAGRAM SHOWING THE CUTTING OF THE SLOPING ENDS OF METALLING EXPERIMENT III

FIG.—14(a)

Figure 15.

Showing the breaking of moist clay clods with the back of the spade and then with a *thapi*.

Figure 17.

A photograph of mile 10 in April 1940.
Experiment III.

CORRESPONDENCE.

Comments by Mr. W. L. Murrell, O.B.E., (Bihar).

My personal view is that by far the most important road problem and necessity in India today is that of the balancing of the road system by the rapid development of a "minor triangulation" or network of minor roads suitable for both motor transport and fairly heavy cart traffic.

And the situation is extraordinary in that, though we are now getting some money to construct these minor roads, the road experts do not agree as to the best types to be adopted. We are as people who have suddenly achieved moderate wealth, but who do not understand how best to utilise it.

In short, the problem of the minor road is our major road problem.

It is suggested that there are two reasons why we have not reached agreement:—

(a) Some of us still believe that the steel tyre is inevitable for future India.

(b) So many of us do not understand soil stabilisation, and are, therefore, shy of adopting it.

Many of us and the number is increasing, believe that the future lies with the village-made broad wooden or other non-cutting tyre, and also with the pneumatic cart-tyre. We refuse absolutely to be resigned to the idea of the continued dictatorship of the steel tyre. All such will doubtless agree that Mr. Mehra's work and his Papers written for the Roads Congress are of great national importance.

Of the six experiments, No. I is a classic and Nos. III to VI will be most helpful to those who are concerned in pavement-widening projects.

As regards Experiment V, pavement widening was commenced on these lines in Chota Nagpur some four years ago and has been very successful. In Chota Nagpur, no specially stabilised soil foundation was used as the berms had been stabilised by receiving road grit for many years past.

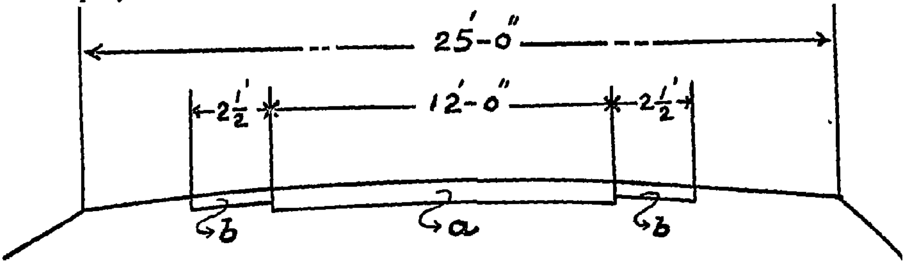
It is Experiment I that I wish to connect with the low-cost or cross-country minor road of the future. With the abolition of the steel tyre, we or our successors, will be able to construct wider and thinner pavements in brick metal, *kunkar*, mooram, crushed rock, and gravel, that will be able to stand up to fairly heavy cart and motor traffic.

Mr. Mehra brings to us a cheap type suitable for light traffic which can quickly be converted, with increasing traffic, to a type suitable for fairly heavy traffic like the types just mentioned, but superior to them in that it will be dust-proof.

The special point about this cheap type is that it will be cheapest in the large tracts covered by great Government irrigation projects and where a good system of minor roads will fetch the producer higher prices and help him to pay his water rates. It is in these very places that mooram, crushed rock, and gravel are generally unobtainable.

The following cheap type is based on Mr. Mehra's Experiment I.

Specification :—



(a) Foundation and wearing courses, *vide* pages 141 and 142 of Paper H-40. (b) Wearing course, *vide* page 142 of the Paper.	Stabilised earth.

Cost per mile :—

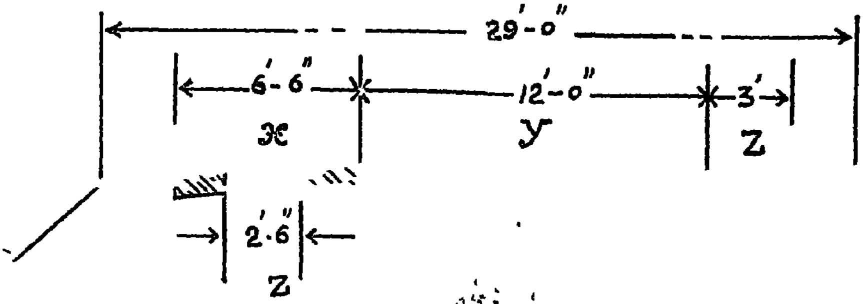
$\frac{12 \text{ Feet}}{9 \text{ Feet}} \times$	Rs. 2,000/-	=	Rs. 2,666/-
2 berms × 2½ Feet		=	Rs. 400/-
	say		Rs. 3,100/-

If we want the higher type for fairly heavy traffic, or desire to utilise the above sketched type for increasing traffic, all we need do is to prime and surface-treat the central 12 feet of the above type.

Cost per mile :—

(a) Stabilisation as above.	=	Rs. 3,100/-
(b) Priming at Rs. 1/8/- and surface treatment at Rs. 5/- per 100 square feet	=	Rs. 4,120/-
say		Rs. 7,200/-

If I were complacently resigned to the dictatorship of the steel tyre, however, I would suggest something like the following as the section to compete with both those given above.



Specification:—

X—Cement concrete trackway for loaded carts, unloaded carts leaving the trackways and passing on the stabilised earth pavement.

Y—Pavement, *vide* Experiment I.

Z—Berm, etc., stabilisation, *vide* Experi-

Cost per mile :—

X	—	Trackways.	.. .. =	Rs. 9,000/-
Y	—	As above. ..	.. .. =	Rs. 2,660/-
Z	—	$\frac{5.5 \text{ Feet}}{5 \text{ Feet}} \times$ Rs. 400/-	.. .. =	Rs. 440/-
		Extra width formation.	.. .. =	Rs. 100/-
				Rs. 12,200/-

In case double trackways had to be provided later, the cost would be Rs. 21,000/- per mile.

The above figures are based on

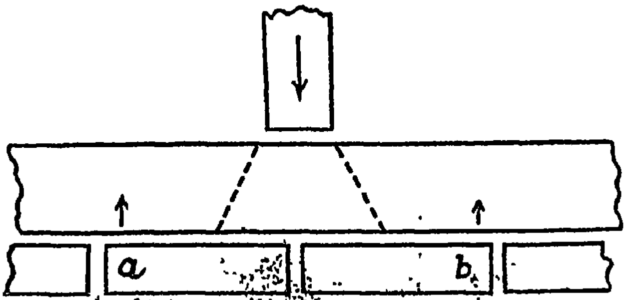
Aggregate for concrete at about Rs. 30/- per 100 cubic feet
And chips at about Rs. 38/- per 100 cubic feet
As well as on Mr. Mehra's Figure 12.

Equated payments and maintenance costs are not discussed, as Mr. Mehra is naturally not yet in a-position to give these for stabilised earth roads, either plain or surface-treated. Also I, at present, believe that the Rs. 150/- per mile stated in Table I Paper D-40, page 52, would be insufficient to cover the maintenance of the trackways, to say nothing of the stabilised earth surfaces.

The comparison is made, not only with a view to bringing out the point that the minor road network could be greatly expedited, with the limited funds available, by the use of earth stabilisation, but also with a view to showing the necessity of replacing the steel tyre by village-made "balloon" wooden and fabric tyres as soon as possible.

2. As regards Mr. Mehra's statement that the use of brick soling is an absolute waste of money, I would like to express some difference of opinion.

If one considers a wheel load coming over the joint between two bricks



so that the outer ends 'a' and 'b' of the bricks tend to rise, I suggest that there is sufficient friction at the ends of these bricks, by reason of the sand [illegible] they are generally given, to enable the load to the crushed rock, and gra[illegible] over a width more nearly equal to double the

Besides this, the brick soling performs quite useful functions as described below.

(a) It prevents the earth from the road bed from working up into the interstices between the pieces of metal in the layer of metal, thus lowering the metal surface in those spots where the bed is more clayey, or where there are segregations of larger pieces of metal.

This differential vertical movement of the wearing course is prevented in some countries where stone or brick soling has been dispensed with under water-bound surfaces, by first spreading in the road bed a thin layer of cheap small aggregate before placing the road metal, in order to avoid this differential penetration from below, or differential settlement from above.

(b) The brick soling is a most reliable tell-tale when the wearing coat has gone.

3. On page 144, Mr. Mehra states "It is possible to surface-treat this stabilised pavement after applying a suitable tack coat."

Doubtless Mr. Mehra means a priming coat, so that the bituminous material will penetrate the stabilised earth, as well as make the surface "tacky" to receive the surface treatment. If only a tack coat (non-penetrating) were used, traffic would soon cause a dust film under the surface treatment which would then quickly peel off.

4. I would like to make a few remarks about the excellent, if necessarily rather hurried, demonstration* by Mr. Mehra at which members of the Council and Sub-Committees were present at Delhi in January 1941.

Mr. Mehra showed us the technique of sieve-testing, obtaining the liquid limit, plastic limit and plasticity index, etc., of a soil so as to enable one to catalogue it in its right place for use as a material for road work, and he stressed that it should be the more practical tests such as these which should receive our consideration.

To me it seemed that the tests, if practical, were rather lengthy, and took much time.

In 1939, I inspected the soil-testing arrangements of the eastern states of Australia and was struck with the comparative simplicity of those adopted in Queensland. These are described in the Collections No. IRC 62 of the Roads Congress Library, but a very brief description is as follows:—

To begin with, a fairly large number of widely varying soils is examined minutely for the above-mentioned soil characteristics, and the results are carefully kept as pilot or control records.

The same soils are then subjected to two additional but *fairly quick* and very simple tests known as the [illegible] test and the miniature abrasion test.

For the [illegible] uses [illegible] technique [illegible] have [illegible] $1\frac{1}{4}$ inches, and a

drying oven and, for the latter, a number of tin moulds $1\frac{1}{2} \times 1 \times 1$ inches and some square, screw-top jam jars about $5 \times 3 \times 3$ inches mounted, like the cylinders of a Deval rattler testing machine, on an axle turned by hand.

To make the linear shrinkage test, sufficient water is added to the soil so that it will just flow into the long, greased mould. The sample is then dried in the oven and the cracks or spaces are measured as a percentage of the length of the mould.

The miniature abrasion test is equally simple.

Sufficient water is added to the soil so that it will flow into the small moulds, and the samples are then dried in the oven. Four samples weighing W_1 in all are then put in a jam jar and the jar is rotated for 100 turns at 30 to 33 turns per minute, and then taken out and again weighed. If W_2 be their total weight after extraction from the jam jar, then the miniature abrasion loss is $\frac{W_1 - W_2}{W_1} \times 100$ per cent.

It is all very simple. Without the weighing scales, the equipment would not cost more than Rs. 80/-.

Now these two results, the linear shrinkage percentage and the miniature abrasion loss percentage, are recorded along with the other information for each of the pilot specimens.

Then whenever anyone, engaged on a project, wants to know the liquid limit, plastic limit, plasticity index, etc., of any other soils, only these two quick tests are carried out, and the results are compared with the equivalent records of the pilot or control specimens.

It has been found that it is good enough in practice to quote the respective liquid and plastic limits, plasticity index, etc., for the control specimens which possess similar linear shrinkage and miniature abrasion loss percentages, as being those of the samples received from a project.

I would like to suggest that this system should be adopted also for India where the number of specimens, we will have to examine, will run into some thousands annually. The collection of information for control records could be dealt with centrally, and copies could be supplied to the provinces who would do their own miniature abrasion and shrinkage tests.

Queensland also supplies those engaged on project work with a numbered colour chart. Comparison of the colour of the project sample with that of the control sample speeds up the identification of the project sample when looking for a control with which to match the project sample.

5. There is even more in this soil testing than the collection of information for the stabilisation of road surfaces.

When designing any pavement, one of the most difficult matters, and one that vastly affects the cost of the project, is to determine the pavement thickness.

Taking [illegible] large, as we do in the case of bridge design, the thickness of [illegible] depends on the bearing power of the road

bed and so, the more stable the soil in the road bed, the thinner and cheaper can the pavement be made.

The Queensland Main Roads Commission have worked out a chart, vide No. IRC 62 in Indian Roads Congress Library, from which the economical thicknesses of water-bound and concrete pavements can be read off as soon as the liner shrinkage percentage, the field moisture content and the percentage material greater than 3 millimetres in the road bed are known.

The chart is applicable to soils of all kinds; and its eventual adoption here might save much, even on one project.

6. I hope, Mr. Mehra will some day soon give us something equally practical on soil stabilisation with cement and with molasses-cum-lime.

Reply by Mr. S. R. Mehra (Author), to the above comments.

I think, I can compliment myself in having converted, as a result of three years' sustained effort, one of the foremost among those highway engineers who are genuinely interested in the great problem of low cost roads for India, to the view that it is not an impossible problem and that there is a reasonable chance of finding a solution.

As regards the pavement widening in Chhota Nagpur on the lines of Experiment V, I should like to utter a word of warning. This is really covered by Experiment IV *viz.* Elimination of Soling, and the five rules laid down in the description of Experiment IV must be carefully observed. Otherwise, the venture may result in discouraging failures, due to unsuitable subgrades.

The non availability of mooram, crushed rock, and gravel in most areas under irrigation is recognized. But there is always the good old brick to fall back upon, which is available all over the country. As already mentioned in my Paper, I am trying to evolve a cheap method of burning clay sticks, which will also be cheap to break to proper size.

The various alternative designs, suggested by Mr. Murrell for different grades of traffic, are very interesting but the main thing is to put them all to practical tests. It is only by undertaking bold experiments intelligently, that we can hope to come to definite conclusions. This is the only way of removing the scare of soil stabilization.

So far as the question of maintenance costs is concerned, it is useless for me to try and assert that the figures given by me are correct, unless I have an opportunity of putting before the Congress, actual figures for a length of at least a hundred miles. My experience of the maintenance of the miniature Experiments I have been able to carry out, however, indicates in its own small way, that my figures should not be far out.

I am afraid I have no sympathy whatever for brick soling, except in the case of fresh embankments where the subgrade [illegible] be properly compacted and consequently it is desirable [illegible] have [illegible] area of contact of the load with the subgrade [illegible] case the [illegible] is more [illegible]

useful due to its larger area of contact. The brick-on-edge for soling should, therefore, be entirely forgotten and the flat brick should be used with reserve.

Mr. Murrell, in his attempt to justify the use of brick soling, has unconsciously brought forward a point against its use, which I omitted to mention in my Paper. As illustrated in his diagram, the end 'a' and 'b' of the two adjoining bricks will tend to rise for the position of the load as shown in the same diagram. This will naturally help to reduce the effective weight of the crust at 'a' and 'b' and consequently lower the supporting power of the crust, which, in an elastic pavement like water-bound macadam, etc. depends mainly on its weight (thickness).

Further, from the same diagram it is clear, that the ends of the bricks, directly under the load, will tend to go down, thus concentrating the load over a small area of brick instead of dispersing it.

If it is assumed, that the joints between the bricks are filled with sand, as stated by Mr. Murrell, I suggest that there is hardly any friction whatever. The friction in this case is a direct measure of the shear strength of the joint between adjoining bricks, which, in the case of a cohesionless mortar like sand, is nil. Even if the joints were filled with a cohesive clayey soil, it will more often than not be in a damp state due to the capillarity of the subgrade, and as such, have very little cohesion.

Mr. Murrell states that one of the advantages of brick soling is that it prevents pieces of metal from penetrating into the subgrade I have already agreed that if the subgrade is liable to softening, brick soling is useful. But it must be flat brick soling.

I agree with Mr. Murrell that the tack coat for surface treatment should also penetrate into the surface or 'prime' it to an extent. But the main object being to make the surface 'tacky' the expression tack coat is used. Perhaps someday when we have made enough progress in soil stabilization and are qualified to prepare a glossary of terms, we shall call it 'tack primer' or something like that, to end an argument.

The simple tests related by Mr. Murrell, which are said to be in use in Australia, are very interesting. I am looking into these and will perhaps, in course of time, be able to report on the result of my investigation. I am thankful to Mr. Murrell for pointing this out.

The possibilities of cement and molasses as soil stabilization materials are under examination. But due to the limited resources of my private laboratory, it takes me much longer to get down to a problem than would be the case with a properly equipped laboratory, and as such, I can only say, that a report will someday be made on this point also.

PAPER No. I—40

NOTES ON

DRAG SPREADING AND DRAG BROOMING

(with plans for inexpensive, country-made plant, and with specifications)

BY

MR. W.L. MURRELL, O.B.E., B.C.E.(MELB.), A.M.INST.C.E.,

Superintending Engineer, Public Works Department, Bihar.

These notes commence with a confession and an appeal.

The confession is that, owing to the writer's ignorance of these two methods, he has in his time, wasted many tens of thousands of rupees by rooting up and re-sectioning roads that did not really need to be so treated.

The appeal is for senior engineer officers to get junior engineers interested in both methods, so that they will eventually be applied in their respective fields, more or less as routine procedure.

To start with, it would be unnecessary and fatal to treat drag spreaders, drum mixers, drag brooms, and kerosene-tin pourers as tools and plant required for the general use of a division.. There may be great delay in getting sanction and funds. The Government of India Public Works Account Code paras 174 (b) and 216 (b) enable such tools to be charged direct to works estimates, even for repairs. If the estimates are small, a drag spreader may be charged to one estimate, a drag broom to another and so on. Nor should there, at first, be too much insistance on the accuracy of estimates for these new kinds of work. Red tape kills progress. It should suffice that any item of work, the cost of which cannot be foreseen accurately, should be done departmentally under responsible direct supervision, all necessary information being recorded.

There are generally one or two officers keener on road work than the rest, and these might best be given such work, an attempt being made to lighten them of a few normal duties.

Once a system or method has been understood and is being smoothly worked to (and not before), other engineer officers should be encouraged to inspect, any necessary facilities being allowed to them. There is nothing like a practical demonstration. Notes like the present one, and plans, take time to read, and very rarely do they by themselves convince or encourage.

DRAG SPREADING OF PRE-MIX

The practice of "drag spreading" is simply and essentially a method for the improved laying of a pre-mixed chipping carpet by means of a blade, placed at right angles to the road, each end of the blade being carried on a sledge-like skid or runner placed lengthwise with the road. The blade and the two runners constitute the drag spreader, which is pulled along the road.

There are two kinds of drag spreader:—

(*a*) The light or hand drag, Plate No. 2. In this case, the drag is pulled along by men, whilst other men pour the pre-mix on the road surface in front of the blade.

(*b*) The mechanical drag.* In this case, the drag is pulled along by the motor truck which has brought the pre-mix from the mixer and which, while towing the drag, pours the pre-mix on to the road surface in front of the blade by means of a body-tilting arrangement and special tail-board.

This second kind of drag is much heavier, having controls for altering the setting of the blade while in motion, and an arrangement for allowing some pre-mix for special purposes to escape laterally through a gate in either of the runners.

Whichever kind of drag spreader we consider, the practice of drag speading is, without the slightest doubt, by far the most important development in road-work technique made in the last ten years.

This note deals with the light or hand-drag because its construction is possible in any *mofussil* workshop at very low cost, and its use is simplicity itself. The attached plan, Plate No. 2, for which we are indebted to Mr. D. V. Fleming M.I.E. Aust., Commissioner of Highways, South Australia, gives all information necessary for its construction. The drag spreader made at Muzaffarpur cost Rs. 65/-.

Please see the 1 inch = 1 foot drawings, Plate No. 2, and note the "spreading blade", its two "runners" and "draw-bar". The slotted clamp at each end of the blade allows the blade to be raised or lowered with respect to the runner *i.e.*, with respect to the road surface.

Either end of the blade can be placed at the same height above road surface, as the other end, or at a different height.

The road camber is not given on the blade but on the iron or "steel edge" of section 4 inches by ½ inch bolted to the blade. The camber of the steel edge illustrated is 1 inch in 9½ feet; but we can have different, inter-changeable steel edges for different camber, or for no camber.

And that is all there is to it; but perhaps the writer should add that certain users in India have suggested that the top of the blade should be

*For further particulars of the mechanical drag kindly refer to Library Book, Catalogue No. IRC 68.

furnished with a fixed strip of sheet 4 inches by ⅛ inch, curved upwards and forwards so that any excess of pre-mix will not fall to the rear of the blade, but will be thrown forward in the directoin of motion.

Now about the pre-mix.

The writer will confess that it is not so very long ago that the word "pre-mix" frightened him out of touching any pre-mix specification. For him, this word was associated with great difficulty in obtaining expensive plant, and trouble in keeping it going.

This fear is now a thing of the past, thanks to the "home-made" revolving drum mixer, a constructional sketch of which is attached, (Plate No. 3). Such mixers cost about Rs. 21/- made in Muzaffarpur, and will last a long time. The design was originally prepared by one of the binder companies and we should be grateful accordingly.

A drag spreader will keep 20 or 30 of these drum mixers going but, for a small job of half a mile or so a dozen mixers should suffice.

A power roller is, of course, necessary. The ordinary medium-to-light roller is preferable, with the usual quick reverse so that the spread material will not be squeezed out from under the rollers by there being too long a stationary period. A differential on the roller also helps, so that the roller can turn fairly sharply without unduly "screwing into" the spread material, but it is not essential. All this, however, refers equally to the consolidation of any bituminous material.

The uses of the drag spreader are :—

1. To spread pre-mixed material evenly over an even road surface to a uniform depth. This is obvious. A light drag can spread up to 2 inches (consolidated) depth, and a mechanical drag up to 4 inches, at a time.

2. To spread pre-mixed material over an uneven surface, so that the top surface of the pre-mix is even. This is not so easy, as the effect of consolidation has to be considered.

Here please refer to the diagram illustrating the theory of the drag re-sheeting process, Plate No. 1, for which we are indebted to Mr. S.L. Luker, B.Sc., A.M.Inst.C.E., of the Department of Main Roads. New South Wales, who is the chief pioneer of this technique.

It will be seen from Plate No. 1, diagram 3 that, where the original road surface is very uneven, the consolidated pre-mix will also be uneven, though to a less extent.

Therefore, for rough surfaces a *smoothening course* must be done first, *vide* diagram 6, Plate No. 1.

As a general rule, a second or *wearing course* suffices for completion of the job ; but there are cases on record where the original road surface was so very rough that an "intermediate" course was done.

In the case of corrugated or other rough road surfaces, it is possible to complete the job with a smoothening and a wearing course, even though the crests of the bumps may be as much as two inches above the troughs or hollows. On the average, the material to be allowed for expenditure in this smoothening course, where necessary, is taken as 0.6 inch consolidated depth over the whole area treated. The consolidated depth of the wearing coat is from 0.5 to 0.75 inch over the bumps.

It will now be seen that drag spreading has an enormous advantage over surface treatment in that a smooth surface results from the former, whilst simply painting an uneven surface and then putting chips on it, merely reproduces all the original bumps and hollows of the old surface, especially when the surface treatment is not done with cold binder, and a roller dragging a broom.

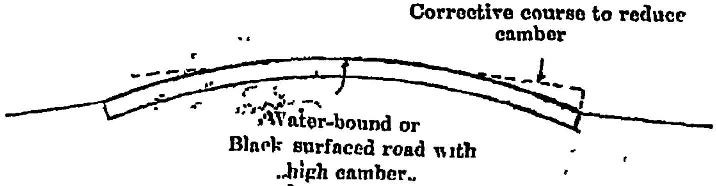
This smoothness of surface is now being recognised as of the utmost importance, as it has been found that a road to carry fast traffic can be made very cheaply if only the surface is smooth. The point is that bumpy surfaces cause traffic to transmit to the base course and sub-grade exceedingly great forces which do much harm, so that the surface becomes still more uneven, and maintenance charges are increased. The engineer must also consider the comfort and safety of road users.

A most important fact about these thin, pre-mixed, drag-spread chipping carpets is that they can do much higher duty than the surface-treated road, and this is especially so when the chips are very tough and hard They should last at least twice as long as a surface-treated road. Conversely, chips that are likely to crush, should never be used in pre-mixes. They might be used to a very limited extent only for surface dressing and road mix seal.

3 The third and the last main use for the drag spreader is in the correction of camber without rooting up the roadway and resectioning it at considerable cost and great inconvenience to the public.

Most engineers are now finding that the camber which was necessary for water-bound surfaces is too much for surface-treated or other bituminous surfaces. High speeds are making these high cambers positively dangerous.

The trouble is that we have so many miles of high-cambered water-bound macadam that a cheap means must be made available for reducing the camber. The drag spreader provides this means.



In this case the drag spreader does a *corrective course* simply by our raising one end of the blade more than the other. Super-elevation can be

given or increased in the same way, and camber can also be increased by central dragging with a curved steel edge.

All this applies equally to surfaces other than black-topped surfaces. Water-bound surfaces can be so treated if first primed, and cement concrete can also be treated if given cut-back tack coat.

Another great advantage in not rooting up the old pavement and re-sectioning it, is that the old tried-out road surface makes a much more reliable base course for the new surface. The re-sectioned water-bound macadam may have been consolidated with a very heavy roller; but only prolonged traffic through the varying seasons can really produce final consolidation.

The above are the main general uses of the drag spreader ; but it is necessary to remember a few general principles about pre-mixes, apart from drag spreading, before mapping out any programme of work with a drag spreader.

Many will know all about what follows immediately below ; but this note is also written for our youngest members in the Roads Congress.

PATCHING

Pot-holes, or breaks due to old pipe-line excavations etc., should be patched as the first operation. These should either be done in water-bound macadam, well rammed, or else filled and well rammed with a pre-mix. On no account should these repairs be done by grouting as this practice subsequently leads to most troublesome "fat" or "high" spots in the finished roadway.

GRIP ON THE BASE COURSE

When a wheel passes over a thin carpet, it tends to squeeze the material out side-ways, so the material needs to stick well to the base course. However, when this material is a pre-mix, it usually contains only sufficient binder to stick its ingredients together and there is not, or should not be, enough binder to spare to "wet" and stick to the base course.

Hence the base course should be treated with a binder before the pre-mix is spread. This is done, either by giving a tack coat which simply covers the base course, or a priming coat which both penetrates the base course and also leaves its surface sticky.

This prevention of sideway movement is considered so important that, when reducing camber by the corrective course method, it is usual to cut a groove one inch or so deep and wide right along the old pavement at a distance of a few inches from each of its edges.

Grip is likely to be affected also by the subsequent formation of a "dust film" due to the crushing of materials in the base course. Therefore, it is inadvisable to use a thin chipping carpet over material which

is inclined to go to powder, unless one thoroughly treats the base course with a good, penetrating, sticky primer, and lets it get well into it before drag spreading.

PRIMING

This must be done for all water-bound surfaces before a chipping carpet is allowed, but care is to be taken that excess of bitumen does not remain on the surface of the base course, as it might soften the chipping carpet. The following cold primers have all been proved:—

Shell Primer No.2, Socofix Primer No.1, Cold Tar Primer, and doubtless the companies will improve even on these. The rate of application is 20 to 25 pounds per hundred square feet, but it depends on the texture of the water-bound surface and the materials in the interstices of the stone.

TACK COAT

This should be done for all black-top and cement concrete surfaces before a chipping carpet is applied. Bitumen emulsion or tar or bitumen cut-back at 10 to 12 pounds per hundred square feet should suffice. Excess will soften the chipping carpet.

WATER-PROOFING

No pavement can last unless it protects the base course (if water-bound macadam), or the sub-grade, from percolation of water from the road surface.

It must be remembered that the pre-mix put down by the drag spreader in the wearing course is only 0.5 to 0.75 inch thick and, even in countries where engineers have all facilities for tight control of the grading of the aggregate, they cannot guarantee that this thin course will be water-proof. They do their best by putting on very fine aggregate when the rolling is nearly complete, and rolling this into the interstices but, even so, water-proofing cannot be guaranteed.

Of course, priming and tack coating the base course will help to keep the sub-grade dry, but it is desirable to keep the water out of the chipping carpet also as much as possible, especially if the stone chips are inclined to be hydrophile so that stripping of the bitumen may eventually result.

To this end, grading should be attempted as much as possible Water-proofing can also be helped by brushing on small chips $\frac{1}{8}$ inch to $\frac{1}{4}$ inch size just before the rolling is completed, and by finally spreading and rolling even smaller aggregate. $1\frac{3}{4}$ cubic feet per hundred square feet should be ample for this. Mr. Shannon (Burmah Shell) recommends coarse sand or $\frac{1}{8}$ inch chips in preference to $\frac{1}{8}$ to $\frac{1}{4}$ inch, possibly followed by a light seal.

The only positive means of water-proofing the drag-spread chipping carpet itself, is to give it a thin coat of binder at about 15 pounds per hundred square feet and spreading fine chips or even coarse sand at about 2 cubic feet per hundred square feet, and then rolling.

Where drag-spreading is used simply for the correction of a surface, that is already water-proofed, it is better to leave the drag-spread carpet without any seal-coat, as the unsealed surface has a high non-skid value.

GRADING OF AGGREGATE

(For thin chipping carpets).

Not only does grading help to make the carpet water-proof but, if the carpet is drag spread, it makes the spreading even easier.

In none of the drag spreading the auther has seen in India, has grading of the aggregate been even attempted. The chips were rather too large, and with little variation in size, and of flat characteristics. That the drag spreader has coped quite successfully with such stuff shows what a wide margin of safety is entailed in its use.

In making this note, it is the writer's object to refrain from writing any thing which looks complicated, and which might make road engineers shy of adopting either chipping carpets, or the drag as a means of spreading them. He would rather get drag spreading started throughout India with pre-mixed chips of any old grading, than do anything likely to hinder the general adoption of the drag spreader.

Therefore, the following sieve analysis for a wearing course, ½ inch to ¾ inch thick, which has been found to be fairly water-proof, is given simply for information and not in any way as an indispensable specification.

						Per cent approximately.
Passing	1"	dia holes	retained on	¾"	dia. holes	15
Passing	¾"	dia. holes	retained on	⅜"	dia. holes	22
Passing	⅜"	dia. holes	retained on	¼"	dia. holes	15
Passing	¼"	dia. holes	retained on	⅛"	sq. mesh	14
Passing	⅛"	sq. mesh	retained on	$\frac{1}{32}$"	sq. mesh	14
Passing	$\frac{1}{32}$"	sq mesh				17

There are, however, two fundamental principles about the size of chips :—

(1) In the smoothening course, and in the corrective course when done, chips can be larger and the percentage of large chips can be a good deal higher than as shown in the above analysis for a wearing course.

(2) In order to prevent lateral movement in the wearing course, the size of the larger chips should be as large as the drag spreader can

conveniently spread. Thus, for a $\frac{3}{4}$ inch consolidated carpet, the sizes of the larger chips could be slightly more than those given in the above analysis and, for a $\frac{1}{2}$-inch carpet, slightly less.

Should it appear that the chips supplied are all too much of the one size, it is a useful tip to remember the procedure of screening out the smaller size and then hand-breaking a portion of the larger size. It is useful to keep the larger and smaller chips separate until they are fed into the drum mixer, (*vide* specification, page 176) to prevent "balling up" when mixing graded aggregate.

The grading of the chips, and the introduction of fine mineral material prevent the realisation of the non-skid surface. If such a surface be desired at the expense of water-proofing the carpet, materials passing $\frac{1}{8}$ inch square mesh should be omitted, or the carpet should be surface-dressed.

BINDER

Though hot mix, with hot aggregate and hot binder, is often used with the large, overseas mechanical drag spreader, it is customary, in order to simplify the plant, and in order to prevent the risk of premature "setting-up", to use cold mix for the light drag spreader

If an emulsion is used, it should be of the medium-curing type, like " Colas-mix ".

If a cold cut-back is used it should be of a fairly quick-curing type.

A mixture of heated cut-back and unheated aggregate can be quite successfully used in the hot weather as was proved by Mr. I. A. T. Shannon who used Shelspra B. S. when trying out the drag spreader on the Dum Dum–Cossipore Road. Indeed, the Shelspra proved much cheaper than the Colas-mix. There are, of course, suitable Socony and Shalimar equivalents for drag spreader pre-mixes.

WORKING OF THE DRAG SPREADER

There is really nothing much to explain as the process is self-evident. A few practical points are dealt with in the attached works specification. Where the road surface to be laid down is wide, and needs to be done half and half, the second half-width is done by running one skid of the spreader along the top of the edge of the first half-width already spread and consolidated. In such a case it is necessary, of course, to lower the spreader blade near the raised skid to an amount equal to the consolidated depth of the first half-width.

The alternative method is not to shift the blade at all but to lay the two half-widths with a gap few inches wide between the two. As the hand-drag has no side-gate and tail-spreader, this intervening space or gap must be hand-spread with pre-mix from shovels. This second method is, therefore, more complicated.

COST

The cost of drag spreading has been shown in the attached comparative table (page 171). The figures are based on the Muzaffarpur District Board work and are very much on the liberal side as none of the staff or labour had seen this kind of work before, and efficiency was not high.

The road concerned (Muzaffarpur-Sitamarhi Road) had been metalled with Pakur stone, which is remarkably hard and without any cementitious value. The wet rolling eventually had to be done with a mixture of sand and clay-moorum but, inspite of this, the traffic soon commenced rooting out the metal, so that the road was becoming very rough. Also the road surface was undulating in places, especially where the embankment had subsided in the 1934 earthquake, and had been raised.

The whole length of 9 miles was, therefore, primed with cold primers, and this made it possible to put a bituminous surface on. Where the road was not so rough, ordinary surface treatment was done. Where the road was rougher, and too rough for ordinary surface treatment, drag brooming with Socofix and chips was done. In the roughest parts, a hot $\frac{3}{4}$ inch pre-mix chipping carpet was drag spread, without any smoother course. A very light seal was given ; but the cost of this is not included.

As the road had become so bad, it was questioned whether it would be better to consolidate with 3-inch new collection, and then surface-treat, or to first prime and then do the treatments described above.

Priming and drag spreading have cost Rs. 1.9.0 plus Rs. 10.0.0 or Rs. 11.9.0 per hundred square feet as against Rs. 9.13.0. plus Rs. 5.13.0 or Rs. 15.10.0 per hundred square feet for reconsolidation and surface treatment.

The saving of Rs. 4.1.0. per hundred square feet is due to the drag spreader. It is small compared with some of the savings which this process makes possible.

Also the drag-broomed and drag-spread sections are now much smoother than the surface-treated sections. They were much rougher before.

ROAD MIX SEAL by means of "DRAG BROOM"
or
"DRAG BROOMING"

A brief history of the process of mixing binder and aggregate in situ on the actual road surface will help one to understand the theory of this process, and the peculiar conditions which govern its practice in India.

It was the Americans who first constructed quite thick bituminous pavements by using the large single blade of the powered grader for mixing on the road surface the materials for the pavement. First they spread the aggregate and, on top of it, they sprayed the binder, and then mixed the lot. They called the process "mix-in-place" If they wanted to water-proof the work, the surface had to be sealed as a separate subsequent operation on top of the mix-in-place.

The Australians adopted the principle of mix-in-place but they made thin pavements with a seal film underneath them, simply by spreading the binder, or much of it, on the road surface before spreading the aggregate. Thus they have a road-mix and a seal in one operation, and they call it a road-mix seal. This is exactly what we aim at in India with our "drag brooming".

Captain R.C. Graham (Paper No. P, Proceedings of the Indian Roads Congress, Volume V,) and Mr. S.A. Amir (Paper No. E-39, Proceedings of the Indian Roads Congress, Volume VI) refer to this as "mix-in-place" work. The description is not apt because it does not mention the word "seal".

With many others, the author, personally, refers to it as the "drag broom process". This term also is not fitting as we "drag a broom" behind a roller in ordinary surface treatment work, especially if we are working with a cold binder and we want to get more chips into the hollows where the binder has tended to accumulate.

Let us then try to refer to this kind of work as a "road-mix seal by broom", or simply a "road-mix seal".

The Australians, after repairing breaks in the road surface, spread the binder as already described. Then the aggregate is placed on the binder and spread out over it with a broom drag to an average depth of anything from one half to one inch. The remainder of the binder is distributed over the spread-out aggregate.

The Australian practice is then to mix, not with the large single blade of a grader, but by means of a special mixer-drag.

Illustrations of these mixers are given in collection No. IRC 69 in the Library of the Indian Road Congress. They are most efficient, but are too involved and expensive for general use in India.

In an Australian road-mixer, there are a number of small, fixed, blades which scoop up the binder and aggregate as the drag moves forward. Both are thus turned over and mixed, and then spread by a following steel edge like that of a drag spreader. The small mixer-blades are kept pressed down on the road surface by springs so that they get fairly well into the hollows and deal with the aggregate and binder sheltering therein. Mixing is completed by only 2 or 3 trips.

The other feature of the machine is that it has a long base, like the drag spreader, so that its spreader-blade acts in the same way as the drag spreader blade. Its spreader-blade can also be made higher on one side than on the other so as to do corrective work on high cambers, super-elevation, etc.

After the second or third trip, the roller partially consolidates, and then fine chips or sand are spread, and the consolidation is completed.

But we cannot afford and could not maintain these road-mixers and the plant to work them. Therefore, we lengthen the broom drag, call it a "drag broom", and make it not only spread the aggregate, but also mix it. A typical drag broom is shown in the enclosed constructional plan, Plate No. 4, (scale 2 feet = 1 inch). It is rather important to have the flat irons at each end for towing purposes. Such a drag broom can be had in Calcutta from any of the big broom manufacturers, *e.g.* The Caledonia Brush Works (*vide* Directory), and costs about Rs. 77/- F. O. R.

The long, stiff, frame with the lower edges of the brushes all at one level, makes the drag broom act as a planer and give a smooth surface. Patent brooms which fold in two for easy transport are useless. They defeat the main purpose as they lack stiffness

Just as tractor and mixer, or auto-patrol with mixer attachment, are accompanied by expensive and complicated sprayers, our drag broom has its counterpart, the kerosene tin pouring can, a plan of which is attached, Plate No. 5.

The drag broom, Plate No. 4, and the pouring can, Plate No. 5, are poor things, but they are our own.

What is marvellous is that such good and sound results are possible, and this seems to be a good opportunity to remember the good pioneering work done in this direction by Mr. C. D. N. Meares.

There are two great defects in this broom-drag, when considered as a mixer :—

(a) The brushes cannot get down into the hollows to a sufficient extent to mix the aggregate and the binder sheltering in them. They are a poor substitute for the small but searching mixer-blades held down by springs on the real machine.

(b) The brushes are not really stiff enough to disturb and rotate the aggregate so as to get it all covered in the binder. To a certain extent we can overcome this by using less viscous binder, and "Socofix" appears to be good in this respect. The other manufacturers of binders can doubtless supply a similar, suitable, cold cut-back. Spreading the large-size chips first also helps.

Another method of ensuring a reasonable degree of mixing is to make many trips with the drag broom, even before rolling starts.

USES OF THE ROAD-MIX SEAL PROCESS

1. For a good, level, existing surface, the best bituminous process for moderate traffic is ordinary surface treatment (with priming where necessary).

For a rough or very rough surface, the best treatment is the drag spreading of a chips pre-mix.

For the surface betwixt and between, which is just too uneven for surface treatment, use the road-mix seal by drag broom process.

2. Corrective treatment.

Where the camber is too high, the large size chips should be spread towards the edges of the pavement, and the smaller over the crown.

THE PROCESS

This has been described by Mr. S.A. Amir in his Paper No. E-39 *vide* Proceedings of the Indian Roads Congress, Volume VI; but a little more information might be useful to supplement what he has written.

If the existing surface is water-bound, most of the binder should be spread over it before placing the aggregate, so as to act partly as a seal. If the surface to be treated is bituminous, only half of the binder need be placed first, so as to act partly as a tack coat.

The grading of the aggregate, placed upon the bottom or seal binder is most important. There should be a good percentage of medium and small-size chips, not for water-proofing as in the case of the drag-spread pre-mix; but so as to afford fine material that will be allowed by the broom to remain on the bumps, while the rest of the small chips go in the hollows with the large ones. Only in this way can one prevent excessive tinkering round with pre-mixed chips on the high or "bald" spots as described by Mr. Amir.

The following is a screen analysis for suitable grading, with a great deal of tolerance :—

Passing	$\frac{3}{4}$"	square mesh.	100	per cent.
Passing	$\frac{5}{8}$"	square mesh.	80-90	per cent.
Passing	"	square mesh.	20-40	per cent.
Passing	$\frac{1}{4}$"	square mesh.	5-15	per cent
Passing	$\frac{1}{8}$"	square mesh.	0·5	per cent.

The quantity of chips required will vary according to the roughness being less if the surface to be treated is smoother.

The quantity of total binder will vary much as the quantity of chips.

Aggregate for covering the rolled surface should be of fine stone screenings or very coarse sand passing a $\frac{1}{4}$ inch but retained on a $\frac{1}{8}$ inch square mesh, spread over the road by means of the drag broom at the rate of $1\frac{3}{4}$ cubic feet per hundred square feet, and then finally rolled in.

The stone for the aggregate for road-mix seal, as well as for drag spread pre-mix, should have a French Coefficient of Wear of not less than 8 wet.

COST

The cost of this road-mix seal work is given in the comparative statement attached (page 171). In this particular case, the figures given should be taken as a rough guide only, as the chips on the Muzaffarpur-Sitamarhi Road job were not well graded, and not quite enough were used for such a rough surface.

THE DRAG SPREADER, OTHER USES.

In the last 2 or 3 years, the drag spreader has been used in Victoria, along with surface penetration methods, for road surfaces that are too undulating to be surface-dressed.

First, the undulating surface is cold primed or given a tack coat, and the dry chips are spread just in the same way as the pre-mix smoothening or wearing course above described, by the drag spreader.

The chips are then penetrated with bitumen emulsion, and rolled and finished as described above for the pre-mix. The idea, of course, is to save the cost of pre-mixing.

It is not quite so simple as it seems.

Though a slow-breaking emulsion is used, so that excess binder will have time to flow down into the hollows where the aggregate is deeper, it is difficult to get enough binder into the thick aggregate over the hollows without getting an excess of binder in the thin aggregate over the bumps, thus leading to "fat spots" later.

The author had been experimenting on much the same lines in 1935, before the hand drag had been developed. On the Patna-Digha Ghat Road, as we then had no cold primers, we primed with hot No. 1 Road Tar and blotted with sand. When dry, we spread chips by means of a home-made planer-drag, and penetrated with either Colfix or Colas, diluting the emulsion with local water. The work lasted a few months only, failing after the author had been transferred. The causes of failure were doubtless the great severity of the cart traffic, the quality of chips used, and possibly the dilution of the emulsion.

The process was not developed as it was referred to a Conference of bitumen engineers in Bombay who opined that the practice had but little hope of useful development.

The author still thinks that under tight control, this system of drag spreading dry aggregate and then penetrating it, may be of use for short lengths where there is but little steel-tyred traffic and where it would not pay to set up mixing plant but, for an easy fool-proof corrective method, he would go straight for the drag spreader and pre-mix, especially where there was little or no steel-tyred traffic.

NOTE

(For both the drag spreading and drag brooming processes.)

When first attempting the processes, it will be better to choose the quantities of materials so that the consolidated thickness of the material *over the bumps will be ¾ inch instead of ½ inch. Operations for the ½* inch cover require a little more skill, especially in the case of Drag brooming, and so should be left till all concerned have spent two or three days on ¾ inch work

ACKNOWLEDGMENTS

In addition to the engineers whose contributions to the technique of these two processes have already been mentioned in these Notes, The author would like to express thanks to Mr. I A.T. Shannon and Mr. W.K. Ashmead who have afforded kindly and constructive criticism concerning drag-spreading and drag-brooming respectively, which has enabled the Notes to be improved.

COMPARATIVE STATEMENT OF COST

Serial No.	Kind of work.	Muzaffarpur cost % sq. ft.	All-India Comparative Formula.
		Rs. A. P.	
1.	PRIMING 21 lbs. % sq. ft.	1. 9. 0.	0.00935 b + 0.56 c
2.	DRAG SPREADING Binder 46 lbs. Chips 12 cu. ft. (% sq. ft.)	10. 0. 0.	0.0205 b + 0.12 A + 3.43 c + Rs 0.20
3.	DRAG BROOMING Binder 41 lbs. ¾" chips 5 cu. ft ⅛" chips 1½" cu. ft. (% sq. ft).	7. 5. 0.	0.0181 b + 0.05 A + 0.015 a + 1.45 c + Rs. 0.18
4.	ORDINARY SURFACE TREATMENT Binder 34 lbs. Chips 5 cu. ft. (% sq. ft.)	5. 13. 0.	0.0152 b + 0.055 A + 1.70 c + Rs. 0.22

Note:—

The Author has suggested the system of All-India comparative formulae to enable any one to quickly ascertain approximately what the work would cost if done in his locality. All he need do is to substitute his local rates for the alphabetical factors, as explained below:—

b = Cost in rupees per English ton of primer or binder at site including all freight and carriage. Except for containers of straight bitumen, it assumes the drums have been returned, and rebate allowed. The weight of the containers is to be excluded.

c = Cost, in decimals of a rupee, of one day's hire of an ordinary local non-expert male cooly. The factor makes allowance for wages

of women and boys as 0.7 times the wages of a man, and the wages of a mate, etc. for labour supervision, as twice the cost of a man, and includes $8\frac{1}{3}$ per cent as contractor's profit on labour.

A = Cost per hundred cubic feet at site including all lead and stacking of coarse chips, expressed in rupees and decimals of a rupee.

a = Cost per hundred cubic feet at site including all lead and stacking of fine chips, expressed in rupees and decimals of a rupee.

Rs = Cost of fuel for heating the binder and raising steam for roller. It also includes all consumable stores for the roller, and wear and tear on hand tools, barriers and lighting etc.

The formulae do not allow for hire charges of roller, drag broom, drag spreader, tar boilers or mixers nor for interest, sinking fund or maintenance, or carriage of such plant, nor the roller driver's pay.

Should any engineer desire to increase the binder say in item 4 from 34 to 42 pounds per hundred square feet, he will use the factor $\frac{42}{34} \times 0.0152$ b instead of simply 0.0152 b. The other items will not be appreciably effected.

SPECIFICATIONS

Detailed specifications follow for each process. In this respect it may appear to be bad policy, when trying to popularise a work process, to set down scores of "shalls" and "shall-nots". Really speaking, however, this specification is a collection of pieces of advice, many of them of minor importance, yet all helping towards turning out a good job. It is hoped that the length of the specification, also, will not frighten those who have not yet used the process

This manner of setting out the advice as a series of formal instructions is adopted so that the text can be used as specifications in contract documents.

So far as the author knows, this is the first written specification for a chipping carpet spread by hand dragging. As regards the road-mix seal process, the author has not seen any descriptions other than those given by Captain Graham (Paper P) and Mr. Amir (Paper E-39) before the Indian Roads Congress Volumes V and VI respectively.

SPECIFICATIONS FOR A HAND-DRAG SPREAD PRE-MIXED CHIPPING CARPET.

For use:—1. Wherever a pre-mixed carpet is to be done.

2. To obviate re-sectioning when putting a light bituminous surface on any road which is too undulating for surface-treatment or for drag-brooming *i.e.* where the bumps, spaced any distance up to 10 feet, are more than ½ inch above the intervening depressions.

3. To correct camber or super-elevation.

PREPARATION OF PAVEMENT

WATER-BOUND MACADAM, SURFACE TREATED MACADAM, OR OTHER BITUMINOUS OR CEMENT CONCRETE SURFACES

Any unevenly graded sections or long undulations shown by an 18-foot straight edge shall be rectified as far as possible. Excessively high bumps shall be cut down, and long depressions shall be built up with macadam, bituminous if the existing surface is a black or cement one.

Pot-holes or similar escarped depressions shall be well cleaned out, primed, and filled with a pre-mix of the largest possible stone, and well rammed.

Fat spots shall be cut out, and the surface restored to the original condition.

Traffic shall be allowed on the road for at least a month after these repairs have been done.

The pavement to be treated shall be dry, and shall be thoroughly broomed to remove all superficial foreign matter.

Except under conditions where injury to the existing pavement would result, pavements having excessive cross-fall shall have grooves about 1½ inches in depth cut on either side, parallel to and at a distance of 6 inches from the edge, or as may be ordered by Engineer in-charge.

PRIMING

Where the surface is of water-bound macadam, it shall be primed with from 20 to 25 pounds of approved cold primer per hundred square feet as decided by the Engineer in-charge. Care shall be taken that there will be no excess of primer left on the surface, such as may lead to fat spots or softening of the carpet. If necessary, the Engineer in-charge will

order in writing that clean coarse sand shall be spread as a blotter. Any such order shall also record the reason for the excess of binder on the surface.

TACK COAT

This shall be of approved bitumen emulsion, or cold bitumen or tar cut-back applied at the rate of 10 to 14 pounds per hundred square feet, as ordered by the Engineer in-charge.

Where the surface is a bituminous one, a tack coat shall be done as follows :—

If the surface be "dry", in poor condition, and inclined to be brittle or showing too much mineral content, or if the carpet is to be only $\frac{1}{2}$ inch consolidated depth over the highest spots, the tack coat shall be done over the whole area of the road to be treated, and similarly for a cement concrete surface.

Where the bituminous surface is in good condition and the depth of carpet over the high spots is to be $\frac{3}{4}$ inch, only the edges of the pavement for a width of 6 inches shall be given a tack coat. Where grooving of the edges is done, grooves shall be treated

AGGREGATE

The stone chips shall be clean, tough, durable, free from dust, dirt, or other foreign matter, and have a French Coefficient of Wear of not less then 8 wet. They shall be free from excess of flat, elongated, or rounded particles.

No aggregate shall be accepted if it is known to have a tendency to strip when used with bituminous materials.

GRADES (not grading) OF AGGREGATE

There shall be two grades, coarse and fine.

Coarse grade shall be that in which the largest chips will pass through a screen of $\frac{3}{4}$ inch square mesh.

Fine grade shall be that in which the largest chips will pass through a screen of $\frac{1}{2}$ inch square mesh.

The coarse grade shall be used for smoothening courses and for wearing courses of $\frac{3}{4}$ inch consolidated thickness over the highest portions.

The fine grade shall be used only for wearing courses of $\frac{1}{2}$ inch consolidated thickness over the highest portions.

GRADING OF AGGREGATE

There shall be two gradings of both the coarse and fine grades, *viz* harsh grading, and proper grading.

Harsh grading shall be that in which the various quantities of the different sizes have no definite relation to each other. Harsh grading is deficient in certain sizes, chiefly small, and has a high percentage of voids. No grading will be accepted or allowed which is so harsh as to result in difficulty, or in unevenness in spreading.

Proper grading shall be that in which the various quantities of the different sizes are such that the voids are minimized.

Harsh grading shall be used in the smoothening course. It may be used in the wearing course if this is to be separately sealed, or if the sub-grade has been water-proofed.

Proper grading shall be used in the wearing course where this is not to be separately sealed, and where there is any doubt about the water-proofing of the sub-grade.

The kind of grading to be used shall be decided by the Engineer in-charge.

STACKING THE AGGREGATE

Stacks shall be made at places at intervals of about 400 feet, and they shall, where possible, be placed on old bitumen container sheets or such like, upon dry, clean, level ground, handy to the roadside. They shall not be placed on the earthen flanks. Stacks shall be covered to prevent their becoming wet when there is risk of rain.

Wherever a proper grading aggregate is used, the larger aggregate should be stacked separately from the smaller, to facilitate mixing.

The aggregate shall preferably be stacked on the leeward side of the road, considering the direction of the prevalent wind at the time when the work will be done, as the mixer drums will also be placed on the leeward side of the pavement.

BINDER

If an emulsion be used, it shall be of an approved medium-curing type.

If a cold tar bitumen cut-back be used, it shall be of an approved rapid-curing type. If any approved binder be used which requires heating, the heating shall be carried out preferably in proper boilers and it shall be properly controlled by thermometer, great care being taken to keep

the temperature well within the maximum allowed by the suppliers of the binder.

The following shall be taken as a rough guide for estimating the amount of binder to be used per cubic foot of aggregate.

	Cold or Hot Cut-backs	Emulsion.
Harsh grading,	$3\frac{1}{4}$ to $3\frac{1}{2}$ lbs.	$5\frac{1}{4}$ lbs. or $\frac{1}{2}$ gallon.
Proper grading.	$3\frac{1}{2}$ to 4 lbs.	6 lbs. or $\frac{2}{3}$ gallon.
	For tar binders add $7\frac{1}{2}$ per cent	

BEFORE MIXING

Samples of the materials and details of the proportions to be used shall be approved of by the Engineer in-charge prior to the commencement of the work, and the details of the proportions shall be adhered to unless an alteration thereof is ordered, in writing, to conform to any variation in the grading, or to suit any special requirements of the work:

MIXING

Mixing shall be done either in mechanical mixers or in a number of revolving drum mixers as described in the attached drawing Plate No. 3.

The mixing drums shall be placed on the leeward side of the pavement, considering the direction of the prevalent wind, and in such a way as to enable materials to be taken to them and from them with the least possible confusion and congestion of movement.

Mixing shall be in charge of an intelligent and responsible person who shall have no other duty whilst mixing, or preparation for mixing, is in progress.

The mixing drum shall be placed on sheets of old iron so as to facilitate recovery of fallen material

Sufficient drum mixers shall be employed to keep the drag moving.

Should it be necessary first to mix water with the dry aggregate to assist mixing with emulsion, or to prevent premature breaking of the emulsion, the water must be clear and reasonably free from salts which may affect the emulsion. Such water, if used, shall be used most sparingly.

Each batch will be of the same size. The respective ingredients shall be handled in containers that will just take the amount of material required per batch, and care shall be taken that no material is in excess or in deficit in any one batch.

Where aggregate is properly graded, care shall be taken to prevent the balling-up of the finer aggregate. Should balling-up occur, the following procedure shall be followed :—

First the larger-size chips shall be mixed with about one-third of the binder. Then the medium-size chips and the second third of the binder shall be added and mixed. Finally, the aggregate, passing ¼ inch screen, and the balance of the binder shall be added and mixed. Balling-up must also be prevented by not mixing for too long a period.

Any pre-mix falling from the drum mixer when unloading shall be loaded along with the next batch, and not be allowed to "set up" or be wasted. The mixers shall be well lubricated, and shall be cleaned out with crude oil at the close of the day's work.

FEEDING THE DRAG SPREADER

The pre-mix shall be carried promptly in clean iron *"karais"* to the drag spreader. The pre-mix shall not be thrown or dumped on to the road in front of the blade so as to effect partial consolidation ; but shall be spread uniformly with *"karai"* kept near the ground.

As the lead to the spreader becomes less, some of the carrying coolies shall be diverted temporarily to other work such as screening, cleaning plant, repairs in the adjacent half of the road, etc.

DRAG SPREADING THE PRE-MIX

The work shall be under an experienced, intelligent mate or ganger, whose undivided attention it shall receive.

Except for the giving of instructions, strict silence shall be observed by all concerned in the work of drag spreading.

The drag shall be well marked by a red flag, at least 2 feet square and at least seven feet high above the road surface, to indicate to oncoming traffic that it must give way. Material spread by the drag but not yet rolled, shall be protected effectively from traffic, pedestrians, and animals.

Spreading shall follow immediately on the giving of the tack coat, or as soon as the primed surface is dried.

SETTING OF THE BLADE

Spreading shall be to such a depth that the pre-mix, when consolidated, will have a depth of either ½ inch or ¾ inch over the bumps. The setting of the blade shall be determined according to the nature of the aggregate, and the thickness of the course to be done, and it is to be checked at intervals by observation of the depth of some consolidated material it has spread.

Those pulling the drag, and the cooly or coolies receiving the pre-mix from the carrier coolies and spreading it in front of the blade, shall wear wooden sandals.

The drag spreader shall be pulled forward with a continuous, slow, motion, depending on the rate of supply of the pre-mix. It shall not be jerked, and stoppages will be reduced to a minimum.

The front end of the near-side runner shall follow a line so marked on the original pavement that the centre of the drag will follow the centre of the road, the straightness of the camber-line or the continuity of the curve being carefully adhered to.

The pre-mix shall be spread in front of the blade so that, when the blade comes to it, the pre-mix will head up against the blade to a height of about three-fourths of the blade height.

Should dragging have to temporarily cease, it shall cease with some pre-mix still heading up against the blade.

Should it be apparent that the delay will be considerable, the pre-mix in front of the blade should be covered lightly with bagging, which should be damp (not wet) in case of cold mix.

Should the stoppage be so long that the pre-mix in front of the blade has commenced to set up, the pre-mix shall be removed and used elsewhere for patching purposes, and fresh pre-mix shall be placed, taking care that it is suitably banked up against the blade before dragging re-starts.

Should any mistake be discovered as to the setting of the blade just after work commences, the pre-mix which has been wrongly spread shall be immediately taken up. If fresh, the material shall be re-spread. If setting up has commenced, the material shall be used elsewhere for patching purposes. and fresh pre-mix shall be used.

Interference with the setting of the blade should be very rare and, if a change is to be made without re-spreading as above, the change shall be made gradually.

Two rakes shall be kept with the drag and, during any stoppage, the dragging coolies shall trim the edge of the spread material or rake over any inequalities in the surface of the spread material. No pre-mix shall be added to or taken from the surface of the spread material.

On no account shall traffic, pedestrians, or animals, be allowed on the spread material before it is rolled. Should such trespass happen by accident, great care shall be taken to PREVENT the depressions in the spread material from being filled with additional material by some well-meaning but ignorant labourer. This is exceedingly important.

ROLLING

This shall follow as soon as possible after spreading, and shall keep pace with the spreading.

The roller shall be a powered one and shall move smoothly, stop without a jerk, and reverse both quickly and without a jerk.

The roller shall be in good condition and shall not drop oil, water, or coal on the surface of the road. The roller shall be provided with scrapers to all rollers and also a means of either wetting or oiling them, to prevent the picking-up of bituminous material.

A differential drive is preferable but not essential. Rolling on curves shall be done after removing one driving pin.

Rolling shall commence at the edge and proceed towards the centre of the pavement. After the preliminary passage of the roller, rolling shall be by uniformly lapping each preceding track by at least one-half of the width of the rear wheel of the roller, and covering the entire surface in this manner. This process shall be continued until the entire surface is thoroughly consolidated, until all roller marks are eliminated, and until there is no perceptible movement of material under the roller. The roller shall not remain stationary on the work for any appreciable time.

On no account will excessive wetting or oiling of the wheels be allowed.

At the end of the day's work, the roller shall pass completely off the work at the newly completed end. The spread material at the end shall be cut off obliquely and clean in a vertical face, with one end of the cut three feet in advance of the other. The longitudinal edges of the work, especially that to connect the other half-width, if any, shall similarly be trimmed vertically. Excess material should be used for filling pot-holes in adjacent road.

The above procedure shall be followed either for the smoothening and corrective courses or for the wearing course, except that, in the former, no trimming of the edges need be done.

SMOOTHENING AND CORRECTIVE COURSE

In the case where such a course is necessary and drag spreading and consolidation have been done as above, the smoothening course shall be thrown open to traffic of all kinds for at least one week. The traffic shall be encouraged, by means of the placing of barriers, during day-light only, to use as much of the width of pavement as possible in order to complete the consolidation of the smoothening course, especially over the depressions of the old pavement.

The pavement shall then be swept to remove all foreign matter; and any appreciable depressions caused by the traffic shall be repaired by the local spreading and ramming of fine pre-mix.

A tack coat at 10-14 pounds per hundred square feet shall then be applied to the 6 inches along the edges or, should the Engineer in-charge deem it necessary, then to the whole surface, for the reception of the wearing course.

WEARING COURSE

This shall be applied as above-described under " Drag Spreading " and " Rolling", either on the treated old pavement or on the smoothening or corrective course.

SURFACE FILLING
(to wearing course)

Before final rolling has been completed as above, grit screenings or sand passing $\frac{1}{4}$ inch square mesh screen, but retained on $\frac{1}{8}$ inch, shall be spread evenly over the whole surface at the rate of about $1\frac{3}{4}$ cubic feet per hundred square feet, preferably by drag broom. Rolling shall be completed, and the road shall be opened immediately to pneumatic-tyred traffic.

CLEANING UP

At the end of each day's work, great care shall be taken to clean all plant and tools that have been used. This will be done with crude oil and bits of old bagging and rags. On no account shall this cleaning be left till the morning of the following day.

On completion of the work, all shall be left clean and tidy, surplus aggregate and binder being kept under watch till removal to the depot or to other works, along with the tools and plant, and old iron sheeting etc.

Empty drums shall be returned promptly to the suppliers or sold in public auction to the credit of the work.

FLANKS, BERMS OR SHOULDERS

These shall be built up and consolidated without delay to help support the edges of the pavement. They shall be given sufficient cross-fall to drain the crest of the road and, where possible, shall be stabilized or covered with gravel, *kankar* or similar material.

MAINTENANCE AFTER COMPLETION

The pavement shall be maintained after completion for a period of three months and, should any local failure occur during this period, the surface affected shall be removed and replaced with material similar to that used on the work.

SPECIFICATION FOR ROAD-MIX SEAL BY MEANS OF THE DRAG BROOM

This specification is for use on water-bound macadam, surface treated macadam, or other bituminous or cement concrete surfaces which are too undulating, considering modern speeds, to be given ordinary surface treatment. On surfaces where the crests or bumps, spaced any distance up to about ten feet apart, are more than ½ inch high above the bottom of the hollows, this method should *not* be attempted; but a pre-mixed chipping carpet should be drag-spread.

TOOLS AND PLANT

KEROSENE TIN CAN POURER

This shall be substantially in accordance with the attached drawing, Plate No. 5.

DRAG BROOM

This, or these, shall be of stiff, durable, construction on the lines indicated in the attached drawing, Plate No. 4. The component brooms shall be of the stiffest possible durable texture, and of the same design. The lower surfaces of the component brooms shall all be in the same plane.

The drag broom shall be furnished with two tow ropes of length about 30 feet and diameter about 1 inch. One end of each rope shall be whipped to prevent unravelling, and the other shall be fitted with a strong hook for quickly engaging or casting off the drag.

ROLLER

The roller shall be a powered one and shall move smoothly, stop without a jerk, and reverse both quickly and without a jerk. It shall be in good condition and shall not drop oil, water, or coal on the surface of the road.

The roller shall be provided with scrapers to all rollers or wheels and also a means of either wetting or oiling their surfaces to prevent the picking-up of bituminous material.

A differential drive is preferable, but not essential Rolling on curves shall be done after removing one driving pin.

BINDER

This shall be of cold medium-curing bituminous cut-back. Socofix has been found suitable for the purpose but, doubtless, the other interests supplying binder have equivalent preparations.

The quantity of binder used per hundred square feet of road will depend on the degree of undulation and on the nature of the binder and of the road surface to be treated. The following shall be taken as an *approximate* guide only.

Nature of Surface.	Total binder required for mixing, excluding reserve of 3 lbs. % sq. ft. Lbs per hundred sq. ft. For ½" thickness over bumps.	For ¾" consolidated thickness over bumps.
Cement-bound or concrete surfaces, bituminous concrete and surface treated or primed macadam surfaces which are just too undulating to be surface treated.	30	35
Cement-bound or concrete surfaces, bituminous concrete and surface treated or primed macadam surfaces which are not undulating enough to require drag spreading of pre-mix, *i.e.* hollows not more than ½" below bumps.	35	40
Unprimed water-bound macadam surfaces which are just too undulating to be surface treated.	40	45
Unprimed water-bound macadam surfaces which are not undulating enough to require drag spreading of pre-mix, *i.e.* hollows not more than ½" below bumps.		50

Note: For first spreading on the road, before spreading the chips, No. 1 or No. 2 Road Tar, applied hot, has been used in lieu of cut-back, *i.e.* as bottom or seal binder, bitumen cut-back being used as the top binder.

AGGREGATE

The stone chips shall be clean, tough, durable, free from dust, dirt, or other foreign matter, and have a French Coefficient of Wear of not less than 8 wet. They shall be free from excess of flat, elongated, or rounded particles.

No aggregate shall be accepted if it is known to have a tendency to strip when used with bituminous materials.

GRADES (not grading) OF AGGREGATE

There shall be two grades, coarse and fine.

Coarse grade shall be that in which the largest chips will pass through a screen of ¾ inch square mesh.

Fine grade shall be that in which the largest chips will pass through a screen of ½ inch square mesh.

The fine grade shall be used on pavements where ½ inch cover is required over the bumps.

The coarse grade shall be used on pavements where ¾ inch cover is required over the bumps.

GRADING AND STACKING OF AGGREGATE

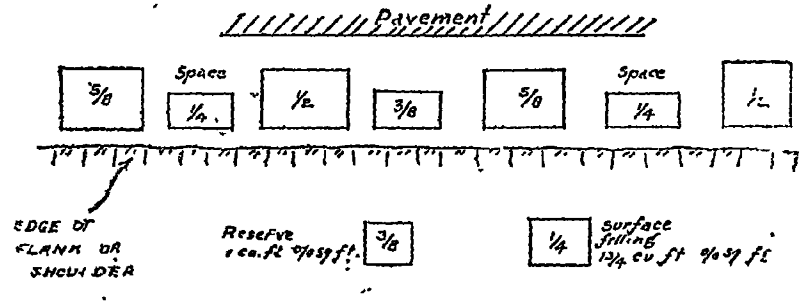
Attention to grading will greatly facilitate the work. Screens shall be of square mesh ⅝, ½, ⅜, ¼, and ⅛ inch in the clear between wires, and used at 30 degrees to the horizontal.

All the material to be used shall be passed through four screens, the material passing the ⅛ inch screen being kept to one side.

The ⅝ and ½ inch screenings shall all be stacked off the flank, and likewise all the ⅜ inch, except about 1 cubic foot per hundred square feet which will be stacked in reserve stacks of 5 cubic feet, off the flank.

Some ¼ inch screenings shall also be stacked off the flank at the rate of 1¾ cubic feet per hundred square feet of road for surface filling, and not for mixing. The balance of the ¼ inch screenings shall be stacked on the roadside flank for mixing whilst drag-rolling, but they shall be stacked near the edge of the formation so as not to obstruct the coolies while hand dragging.

The arrangement of stacks is indicated diagramatically below: —



The ground on which chips are stacked shall be level, smooth, and clear of vegetation, and all the stacks shall preferably be made upon old sheet iron such as that from old bitumen containers.

The $\frac{5}{8}$, $\frac{1}{2}$ and $\frac{3}{8}$ inch stacks shall be made on the flank or shoulder and shall, as far as possible, be placed alternately.

The grading shall be such that for $\frac{3}{4}$ inch work, the total volume of the $\frac{1}{2}$ and $\frac{3}{8}$ inch stacks will be about $2\frac{1}{2}$ times the volume of the $\frac{5}{8}$ inch stacks, and for the $\frac{1}{2}$ inch work the volume of the $\frac{3}{8}$ inch chips will be about twice that of the $\frac{1}{2}$ inch chips.

The following table is meant to be a rough guide as to the total quantity of chips of all sizes required for each kind of surface, as measured in separate stacks.

Nature of existing pavement.	Total volume of chips in cu. ft. per hundred sq. ft. to be stacked on the flank. This excludes reserve 1 cu. ft. per hundred sq. ft. of 3/8 inch chips and $1\frac{5}{8}$ cu. ft. per hundred sq. ft. of 1/4 inch surface-filler material stacked off the flank.	
	For 1/2 inch consolidated thickness over bumps.	For 3/4 inch consolidated thickness over bumps.
Cement, bituminous, or water-bound, which is just too undulating to be surface-treated *i.e.* hollows are not more than $\frac{1}{4}$ inch below adjacent bumps.	7	10
Surfaces as above, which are more undulating *i.e.* hollows are as deep as $\frac{1}{2}$ inch below adjacent bumps.	8	12

Where possible, the stacks shall be placed on the leeward side of the road, considering the direction of the prevalent wind at the time the work is carried out. They shall be placed only a few days before the work is to commence.

It is of the utmost importance that the stacks shall not be placed so as to interfere with the labour spreading the materials, who must use the flanks. In particular, the $\frac{1}{4}$" stacks shall be placed clear so as not to interfere with the coolies when hand-dragging.

COLLECTION OF MATERIALS

Before collection of materials at site, samples shall be approved by the Engineer in-charge, and no deviation from such approved samples shall be allowed unless given in writing by the Engineer in-charge in order to conform to any special requirements of the work.

PREPARATION OF THE EXISTING PAVEMENT

Any unevenly graded sections or long undulations shown by an 18 feet straight edge shall be rectified as far as possible. Excessively high bumps shall be cut down, and long depressions shall be built up with macadam, bituminous if the existing surface is a black or cement one.

Pot-holes or similar escarped depressions shall be well cleaned out, lightly primed, and well filled with a pre-mix of the largest possible stone, and well rammed.

Fat spots shall be cut out, and the surface shall be restored to the original condition.

Traffic shall be allowed on the road for at least a month after these repairs have been done.

The pavement to be treated shall be dry, and shall be throughly broomed to remove all superficial foreign matter. The interstices of the metal of water bound surface should be cleaned out lightly with steel wire brushes so that the edges of the pieces will remain about $\frac{1}{16}$ inch proud. Before applying the binder, the surfrce shall be dusted clean by bagging.

APPLICATION OF BINDER AND FLANK AGGREGATE

Before giving the order to commence the application of the binder, the Engineer in-charge or the person authorised in writing by him to do so, shall inspect the arrangements made, and shall see that there is sufficient binder and also that the quantity and arrangement of the aggregate are correct.

Whilst the surface is being cleaned as aforesaid, the edge of the pavement shall be marked off in equal lengths such that a length multiplied by the breadth of the surface to be treated shall equal in square feet the area which is to be covered by two gallons of binder, assuming that one gallon of bitumen compound weighs 10 pounds and one gallon of tar 10$\frac{3}{4}$ pounds.

BOTTOM OR SEAL BINDER

This work shall be in the charge of an intelligent, responsible, and experienced person, who shall have no other duty whilst the work is in progress.

The binder shall be spread from the above-mentioned kerosine-tin pourers (Plate No. 5), each holding two gallons.

The binder shall be ladelled from the stock container to the pouring can by means of a mug or dipper containing one quart. Great care shall be taken that no binder falls upon the pavement where it will cause an excess, and also that binder is not wasted on the flank of the road. The tray mentioned in the plan shall be used.

The binder shall be poured evenly over the whole surface, except for 2 or 3 inches along each edge. Pouring shall be done by well-practised persons, starting along the crown, and moving smartly back and forth along the road, and *not* across it. Care shall be taken so that there will be no excess of binder on the road as the pourer reverses the direction of pouring.

The poured binder shall then be spread evenly over the whole surface by means of rubber squeegees, or, in the case of water-bound surface, by bass-brooms. The men, who do the spreading, shall be chosen for strength as well as intelligence, and they shall wear wooden sandals.

The amount of binder to be spread on the existing pavement shall depend upon the nature of the surface and the required thickness of the treatment.

In the case of water-bound surface, shall be applied at the rate of about 30 pounds per hundred square feet and, in the case of other surfaces, at the rate of about 20 pounds per hundred square feet.

Should the camber be such that the binder tends to run off the pavement, the binder shall be applied in less quantity.

Where tar is used, the quantity by weight shall be increased by 7 per cent.

SPREADING THE MAIN AGGREGATE

The work shall be in the charge of an intelligent, responsible, and experienced person who shall have no other duty whilst the work is in progress.

The aggegate shall not be spread by the coolies bringing the aggregate. It shall be spread by experienced men to whom the coolies shall hand in it clean iron "*karais*".

The spreading coolies shall wear wooden sandals.

Great care shall be taken that only the largest size aggregate, the $\frac{5}{8}$ inch size for $\frac{3}{4}$ inch work, and the $\frac{1}{2}$ inch size for $\frac{1}{2}$ inch work, is spread at first

This size shall be spread only in the hollows and, to indicate the hollows to the spreaders there shall be at least one man on each side of the road with a light 8-foot straight edge fastened transversely at the end of a bamboo handle of length about $\frac{2}{3}$ of the width of pavement.

The whole of the largest sized chips shall be spread evenly in the hollows, and none on the bumps, before any other aggregate is spread.

In the case of the $\frac{3}{4}$ inch thick work, the whole of the $\frac{1}{2}$ inch chips shall then similarly be spread equally over the whole surface and, when this is done, the whole of the $\frac{3}{8}$ inch chips stacked on the flanks shall likewise in turn be spread.

In the case of the $\frac{1}{2}$ inch thick work, the whole of the $\frac{3}{8}$ inch chips shall be spread equally over the whole area, including the hollows where the $\frac{1}{2}$ inch chips shall have been spread already.

The length which shall thus be covered with aggregate will be determined by the speed of the work and by the rate of evaporation from the binder, which causes it to become more viscous. Doubtless 200 running feet will be done at a time.

During the spreading of aggregate, the next length ahead shall be similarly marked out, and treated with binder ready for the spreading of aggregate.

LIGHT ROLLING TO MAIN AGGREGATE

After the main aggregate is spread, it shall, if of very hard and tough chips, and if ordered by the Engineer in-charge, be given a light rolling of two or three trips.

POURING THE TOP BINDER

As soon as the aggregate has been dealt with as aforsaid, leaving only the $\frac{1}{4}$ inch chips dealt with on the flank, the top binder shall be spread by means of the kerosine-tin pouring can (Plate No. 5), above mentioned.

The quantity per hundred square feet shall be the amount, indicated under para "BINDER" above, less the amount expended as bottom or seal binder, or as ordered by the Engineer in-charge.

For spreading this binder, the edge of the pavement shall again be marked off so that the length multiplied by the width of pavement shall be the area to be treated with 2 gallons of binder, one gallon being taken as ten pounds.

The top binder shall be spread evenly over the whole surface of the aggregate by experienced men who shall have completed pouring the bottom binder on the section ahead. This work shall commence at 2 or 3 points in order to save time. The men spreading the binder shall wear wooden sandals.

MIXING BY HAND DRAGGING

This work shall be in the charge of an intelligent, responsible, and experienced person who shall have no other duty whilst the work is in progress.

As soon as the top binder is poured, mixing shall commence by dragging the broom by hand. The dragging coolies, 3 or 4 on each rope

shall move along the flank on each side of the work, holding the rope near the free end, and moving at a uniform rate without stopping until the end of the work-stretch. By means of a short bamboo, with a hook on the end, one man, proceeding abreast of the front of the drag, shall do any guiding that may be required.

Silence shall be maintained except for the instructions given by the person in-charge of the drag.

The broom shall be dragged so that it bears equally on the road in front and in rear, and also from side to side. This is most important.

The broom shall be dragged back and forth, starting at the edges of the pavement and working towards the centre, till it is seen that all the chips are more or less coated with binder. Six to ten trips should be sufficient to ensure this.

Should mixing be too slow, a man shall load the broom by sitting in the centre, or one man shall be placed at each end of a short ladder secured centrally along the broom.

After loading the broom with men, should it appear that the high places in the old pavement are being stripped of aggregate, or should it appear that the aggregate in the low portions is not being disturbed by the broom and thus covered with binder, dragging shall cease at once for rectification work to be done.

Rectification shall be by placing additional aggregate of the largest size only in the hollows, and covering it with a little binder spread at the rate of approximately 5 to 8 pounds per hundred square feet. Very little should be given.

At the same time, the reserve $\frac{3}{8}$ inch chips stacked off the flank of the road shall be mixed in iron *karais* by means of mason's trowels, with binder at the rate of about 3 pounds per cubic foot, and this pre-mix shall be spread in a thin film about $\frac{1}{2}$ inch deep over the high portions of the old pavement, or over the "bald spots".

Should such rectification become necessary, a report should be submitted to the Engineer in-charge on the evening of the same day, describing the extent of the rectification necessary. The Engineer in-charge should report to higher authority stating whether the rectification was due to materials, enough only for a fairly smooth surface, being used on too-undulating surface, or whether it was due to using the process of drag brooming when, owing to the roughness of the surface, drag spreading should have been done, or giving any other reasonable explanation.

SIMULTANEOUS MIXING AND ROLLING

After 6 to 10 trips with the hand-dragged broom, or after rectification of defects as above, the drag shall be attached to the roller, as close as possible, and as low as possible in order to prevent the front of the drag from being lifted when being dragged.

After the roller has made two or three trips with the drag in tow, and it is seen that the aggregate is being mixed with binder in the hollows, and that the $\frac{3}{8}$-inch pre-mix is remaining in place on the bumps, the remainder of the $\frac{3}{8}$-inch reserve chips stacked off the flank shall be sprinkled over the whole surface, followed by the $\frac{1}{4}$ to $\frac{1}{8}$ inch stuff stacked on the flank. This sprinkling will be given by experienced men wearing wooden sandals.

This spreading of finer aggregate shall proceed whilst rolling and dragging are in progress. The spreading is to be done from iron *karais*, and great care shall be taken that the material is well scattered over the whole surface, as its purpose is to form the matrix. On no account shall there be segregations of this fine material on the road surface as a result of spreading.

As soon as it is seen that this finer material is also coated with binder, and that the surface is compact and smooth, the drag broom shall be removed, and final consolidation shall be done by uniformly lapping each preceding track by at least one-half of the width of the rear wheel of the roller, and rolling the entire surface in this manner.

This process shall be continued until all roller marks are eliminated, and until there is no perceptible movement under the roller. The roller shall not remain stationary on the work for any appreciable time. On no account will excessive wetting of the wheels be allowed.

SURFACE FILLING

Before final rolling has been completed, the finest chip screenings or sand passing $\frac{1}{4}$ inch square mesh, but retained on $\frac{1}{8}$ inch, which was stacked off the flank for this purpose, shall be spread evenly over the whole surface at the rate of about $1\frac{1}{4}$ cubic feet per hundred square feet, preferably by the drag broom, and rolling shall be completed

At the end of the day's work the roller shall pass completely off the finished surface at the completed end.

PROGRESS

The work shall be speeded up as much as possible by keeping the sequence of operations going simultaneously in adjacent lengths There shall be two drag brooms, and preferably more, and care shall be taken that no one operation, such as pouring the binder or spreading the aggregate, may delay the rest of the work.

OPENING TO TRAFFIC

On completion of the surface filling, the pavement shall be opened immediately to pneumatic-tyred traffic. Steel-tyred traffic shall not be allowed to use the surface till after one week

CLEANING UP

At the end of each day's work, great care shall be taken to clean all plant and tools that have been used. This will be done with crude oil and bits of old bagging and rags. On no account shall this cleaning-up be left till the morning of the following day.

On completion of the work, all shall be left clean and tidy, surplus aggregate and binder being kept under watch till prompt removal to the depot or other works, along with the tools and plant, and old iron sheeting. Empty drums shall be returned promptly to the suppliers, or sold in public auction for the credit of the work.

FLANKS, BERMS, OR SHOULDERS

The edges of the completed pavement shall be neatly dressed to a continuous, even line.

The flanks shall then be built up and consolidated without delay to help support the edges of the pavement. They shall be given sufficient cross-fall to drain the crest of the road and, where possible, shall be stabilized with gravel, kunker, or similar local material.

MAINTENANCE AFTER COMPLETION

The pavement shall be maintained after completion for a period of three months and, should any local failure occur, the surface affected shall be removed and replaced with pre-mixed $\frac{3}{8}$ inch chips, well-rammed and finished with finest chips or coarse sand passing $\frac{1}{4}$ inch mesh and retained on $\frac{1}{8}$ inch.

PLATE No. 1.

DIAGRAM ILLUSTRATING THE THEORY OF DRAG RESHEETING PROCESS

EXISTING UNDULATING SURFACE OF PAVEMENT.

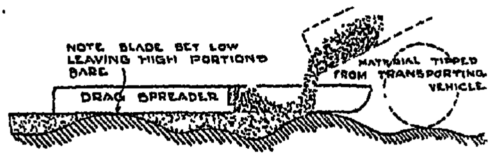
SINGLE-COURSE TREATMENT

SHOWING PREMIX JUST AFTER SPREADING.

SHOWING PREMIX AFTER TRAFFIC WITH SOME UNDULATION DUE TO CONSOLIDATION OF DEEPEST PORTIONS MOST.

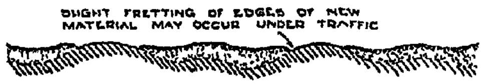
DOUBLE-COURSE TREATMENT

APPLICATION OF SMOOTHING COURSE BY MEANS OF DRAG SPREADER.

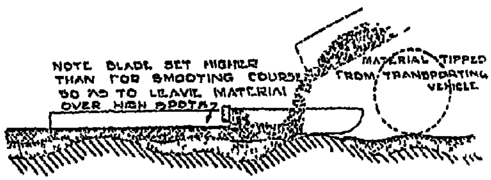


SMOOTHING COURSE AS NEWLY LAID.

SMOOTHING COURSE AFTER CONSOLIDATION BY TRAFFIC.



APPLICATION OF WEARING COURSE BY MEANS OF DRAG SPREADER.

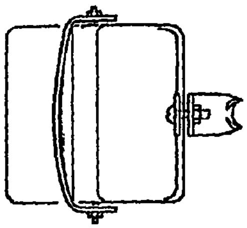


WEARING COURSE COMPLETE.

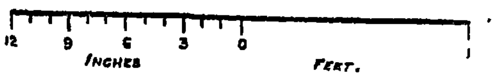
PLATE No. 5.

The Kerosene-tin Can Pourer

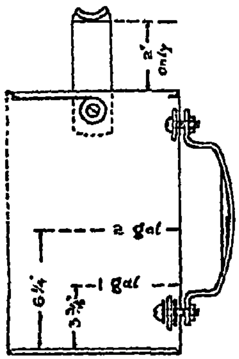
or poor man's spraying-machine.



TOP PLAN



Half the top is cut away to enable can to be filled. Top handle moves to facilitate filling

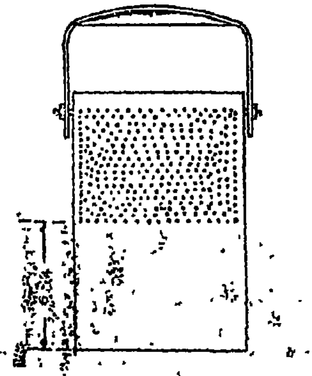


CROSS SECTION

Handles should be well made from iron strip about 2×⅛ with edges curled to facilitate grip. Fastened with large washers and G.I. bolts & nuts Bolt heads to be inside to facilitate cleaning. Lower bolt has two leather washers to prevent leakage.

Perforations should be made by driving a nail right through Size of hole determined by viscocity of the binder Different cans should have holes of different sizes for different kinds of binder. It is better to have the holes made from the inside, with the burred edges on the outside. This effect can be obtained by holing a sheet of tin and soldering it over the necessary gap cut in the side of the tin.

The best method is to drill the holes rather than punch them.



ELEVATION POURING SIDE.

To prevent wastage of binder & to prevent binder being spilled on the road surface thus causing excess, and a subsequent "fat spot", the pouring can, when being filled, should be placed on an iron tray of sheet about 2·6×2·0 with its edges turned up about 2½", reinforced, and soldered.

Cans to be cleaned with crude oil immediately after use, and stored up-side-down.

CORRESPONDENCE.

Mr. W. L. Murrell, O.B.E, (Author):—Cases have recently come to my notice where the available stone chips are good enough for ordinary surface treatment, but not good enough for a premix chipping carpet, as the local steel-tyred traffic crushes the chips and overloads the relatively small amount of binder in the premix. I, therefore, suggest that after the words "....surface dressing and road mix seal." in para 4 of page 160 of the Paper, the following may be added :—

"Where the steel-tyred traffic is very destructive, chips that are fairly suitable for surface dressing for ordinary traffic but not suitable for a premix chipping carpet, would be used in the premix smoothening or corrective course. To finish off, either the best tough hard chips should be brought for the drag spread premix wearing course, or the usual chips should be used in a surface dressing over the premixed smoothening course."

As regards 'Loading', I suggest that the following should be added under "Mixing" on pages 176 and 177 of the Paper :—

Para 5, after "......moving." add the following :—

"With strict control of loading and unloading, eight drum-mixers should suffice. This allows for two at a time being moved forward."

Para 7, after"......one batch." add the following :—

"The containers for the aggregate shall consist of strong but light wooden boxes, each fitted with two handles, so that two men can lift the charge and dump it into the mixer."

"Containers already filled with material for the next charge, shall be ready beside the drum-mixer before the previous charge is unloaded from the mixer."

Regarding "Feeding the Drag Spreader", page 177, someone working on this kind of job once suggested that, if barrows were not available, it would be better to unload the premix from the drum on to a platform which could be lifted out by handles and taken to the spreader. I would, therefore, suggest that the para "Feeding the Drag Spreader" should be corrected to read as follows :—

"After the aggregate and binder are mixed, the premix shall be unloaded into a wheel barrow or portable platform placed immediately below the drum of the mixer."

"If wheel barrows are used, they shall be as wide as possible but so as to pass easily between the two end vertical posts of the mixer, and a plank shall be nailed across the base frame for the wheel of the barrow."

"If a movable platform is used, it shall be substantially to the design shown in Plate No. X-A opposite, page 190 b."

"In any case, the premix shall not be thrown or dumped on to the road in front of the blade so as to effect partial consolidation; but shall be tipped and distributed lightly."

Comments by Mr. S. A. Amir (Bihar).

(1) I hope I am not wrong in thinking that it is for the first time that "drag spread" surfacing work has been introduced to members of the Indian Roads Congress and as such, the author of the Paper deserves our

thanks. From what we have seen of this work as done* in Delhi, it is easy to visualise its scope and possibilities and I feel it is bound to play an important role in future surfacing work in this country also.

(2) As regards the use of drag broom in surfacing work, actual personal experience has brought in me a different feeling. In fact, I wish that the author had not given it an equal status to the 'drag spread' work by discussing and recommending both in the same Paper. So long as I had not done any premix work, the drag broom work with certain advantages over ordinary surface painting work recommended itself, but to those who have done premix work even by ordinary hand-laying, drag broom work is bound to appear less straightforward and more a bother with higher cost and not equally good results.

(3) Doubtless, the author has taken pains to make his notes exhaustive and practical in details. I have no comments to make on the 'drag spread' work of which I have no practical experience. On the other hand, I have done sufficient "drag broom" work under varying conditions and, in the light of my own experience, I have certain suggestions and comments to offer.

(4) The last portion of the second para on page 160 reads thus :— "especially when the surface treatment is not done with cold binder, and a roller dragging a broom."

This indicates that a drag broom, towed by a roller on dry chips spread over a surface painted with cold binder, would tend to level up the unevenness of the road surface. I have grave doubts about this expected result in surface painting job with the help of the drag broom. The chips will be dragged about carrying with them some of the binder and will be left here and there and will not take their proper place till such time as they do not get coated with binder by rolling and turning over in the course of movement under the drag broom. In 'mix-in-place' work, it is only when the chips get mostly coated with binder that the levelling up starts, with more coated chips taking their place in hollows with higher spots left more or less bare which eventually require being covered up with smaller grade of premixed chips. It would, therefore, appear that in a surface painting job with cold binder when coating of chips with binder is not intended, there can be no place for a drag broom for spreading dry chips in such a way as to correct the unevenness of the road surface. The last portion of the para quoted above might well have been omitted.

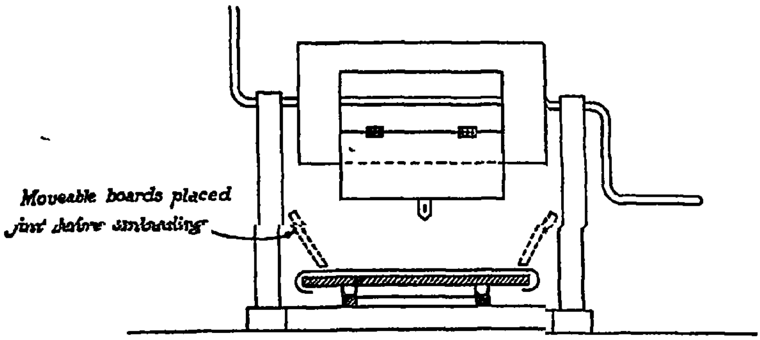
(5) In para on 'Tack Coat' on page 162, I think 'black top' surface includes a primed water-bound surface also. Therefore, it seems desirable to add "including previously primed water-bound surfaces" after "black-top" to make the position more clear as has been done by the author in para one on page 161.

(6) The same objection as mentioned above in the case of the last portion of para 2 on page 160 applies to para 5 on page 166, and this as well might have been omitted altogether.

*Cf. pages 241 to 242 Appendix II, Part 2, Volume VII, Proceedings of the Indian Roads Congress.

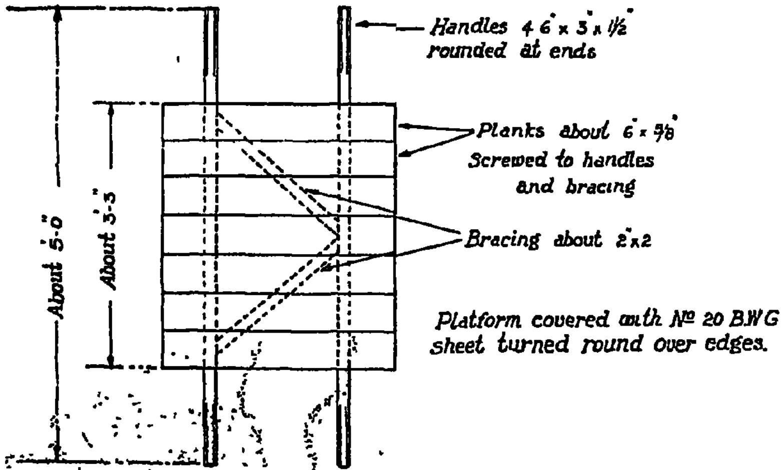
PLATE 3A

PLATFORM FOR REMOVING PREMIX FROM DRUM MIXER
TO DRAG SPREADER



END VIEW OF PLATFORM

In place under the mixing drum



PLAN OF PLATFORM

With No 20 BWG Iron sheet removed

(7) Let us consider the sentence in para 7 on page 166 which reads thus "Then the aggregate is placed on the binder and spread out over it with a broom drag to an average depth of anything from one half to one inch." I doubt about the feasibility of use of a drag broom of a type with which we are all familiar in India in distributing the dry chips, spread over a fluid binder which is to coat the chips on the road. Besides, such uniform distribution, before the chips get coated with binder, is unnecessary, as in the mixing process the chips will be dragged and rolled and will leave the position which they are supposed to take before the next instalment of binder is put over them. In my opinion, the drag broom should be brought in use after the second instalment of binder is laid over the chips spread on the road surface covered with the bottom coat (first instalment) of binder. This is really what seems to be invariably done in this country as will also appear in the sequence of operations given in the specification of mix-in-place work on page 242 of Appendix II, Part 2 of this Volume.

(8) My experience differs a little from what is said in para 2 under "The Process" on page 168.

In surfacing water-bound macadam, somewhat more binder should be laid over the road surface as first instalment than in case of re-surfacing a sealed surface but not 'the most' of the binder as suggested in para 2. If, suppose according to this direction, 80 per cent of binder is laid, which has to be fairly fluid in order to coat the chips spread over it, then the chips will be more floating over the thick coat of binder than if it had been thinner. The action of the drag broom in the former case will be to drag the floating chips wholesale in its front rather than ride over and roll them over in course of being dragged to get coated with binder. Thus, when most of the binder is laid in the first instalment, it would take longer to coat the chips than when, say, 60 per cent of the binder is laid in the first instalment, on the road and 30 per cent as a second instalment over the top of chips spread over the first instalment of binder. After trying different proportions, it has been found that, in case of sealed surface, the tack coat (first instalment) should have 50 per cent and 40 per cent should be laid over chips and, in case of waterbound surfaces, 60 per cent should be laid as tack coat (first instalment), and 30 per cent over chips; 10 per cent in both cases being used in premixing smaller chips for covering up higher and bald spots and for rectification required otherwise.

Of course, whatever proportion of binder may be laid in the road surface, by the time the chips get coated, the road surface below is bound to be fully covered with the binder to act as a seal and the water-bound macadam surface, being more roughish, will naturally retain more of the binder in hollows. I would, therefore, suggest that in this para the words "most of the binder" might with advantage be replaced by "about 60 per cent of the binder."

(9) The third para under "The Process" on page 168 might have been omitted altogether, the reason for which will appear from what is said in discussing the specification for "Spreading the main aggregate," as given on page 186. (See para 13 below).

(10) In the comparative statement of cost on page 171, a mention of the particular binder used on the different works and also cost of labour calculated per 100 square feet in the different cases would have added to the usefulness of this table.

(11) Para under "Drag broom" on page 181 suggests that there may be one or more of this on a job, provided with rope haulage arrangement. It has been found inexpensive that a drag broom may be attached to a power roller in its front with suitably designed steel linkage which may enable it being pulled and pushed in backward and forward runs of the roller, and it gives better results. Having two drag brooms on each job, one provided with rope haulage arrangement and the other with steel linkage, would appreciably quicken the work and cost less.

(12) Para 2, under "Bottom or Seal binder" on page 185, specifies that it should be spread from perforated Kerosine tin pourers. In practice this is found not quite necessary and causes delay which could be avoided. It is more expeditious to use ordinary pouring cans for laying the binder on the road surface and bass brooms and rubber squegees for spreading evenly over water-bound macadam and sealed surface respectively. This paragraph had better been omitted altogether, as the fourth and fifth paragraphs sufficiently specify the operation of spreading binder on the road surface. Perforated Kerosine tin pourer is useful and, in fact, indispensable for laying the second instalment of binder over the top of chips.

(13) Paras 3 to 7 under "Spreading the main aggregate" on page 186 specify the operation of spreading aggregate over the binder laid on the road surface. I very much doubt about the feasibility and practical utility of laying the biggest sized chips in depression and smaller ones on higher spots to start with. In the process of coating chips by drag broom, chips must necessarily be dragged and moved from their original position and rolled over to get coated with binder and the result in practice is bound to be that the bigger and smaller chips if placed in hollows and high spots, will get mixed up and will not be left where they were originally placed. On being so mixed up and coated with binder, it would not be possible for the drag broom to re-sort them so as to leave the smaller chips over high spots and bigger ones into hollows. Experience shows that, to start with, the biggest grade of chips should only be spread first without trying to place them in depressions only. These under the action of drag broom will be all moved and get coated and will take position on the road surface except at the high spots which would be more or less left bare. Depressions will naturally retain chips more than one deep according to the depth. It is for covering the bare high spots that smaller grade precoated chips are required and are placed by hand and on further working of the drag broom (unloaded) are levelled up mostly remaining on the high spots and only surplus going over the bigger chips lying in depresssions and getting lodged in the interstices. Some spots may again be found bare of chips and they require to be covered up with still smaller grade of pre-coated chips. Such sort of tinkering has been found unavoidable in actual practice. Evidently the author of these notes has also been experiencing such difficulties as appears from what he says on page 188, paragraphs 6 to 8.

(14) The direction in paragraph 2 on page 188 under "Mixing by hand dragging" may lead people, new to the job, to think that it is to be worked in the same manner as a roller in consolidation job. This, however, could not be the author's intention. Most of our roads have opposite cross slopes (camber) from the centre line. This makes it necessary that mixing of chips with binder and levelling up is done for each half at a time. A drag broom laying partly on one side of centre line and partly on the other will not bear uniformly and part of it will be ineffective which is not the case with a roller on consolidation job. This paragraph needs modification.

(15) Eighth paragraph on page 188 indicates that such rectification will be an exception rather than the rule. But, as explained above and from what the author says in the paragraphs preceding, it may be taken that such rectification is unavoidable on all work on uneven or corrugated surfaces for which alone such work has to be undertaken. Under the circumstances, the direction for a report, when such rectification becomes necessary, being submitted to the Engineer in-charge on the evening of same day is not likely to serve any useful purpose.

(16) The second paragraph under "Simultaneous mixing and rolling" on page 189 gives an impression that aggregates lying in hollows will start getting mixed with binder after the drag broom attached to the roller has made two or three trips. This, however, is not so. In fact it is in the first 8 to 10 trips of the broom dragged by coolies that mixing of the chips with binder starts taking place and these should get about half to three-fourth coated before the drag broom attached to roller is brought over these. Again, it seems suggested that rectification, if any, will have been done before the mixing of aggregate with binder is completed. In fact, any other rectification, except putting in extra chips (bigger grade) and binder where the broom does not touch and move the chips lying in depressions, if done before the chips get mostly coated, does not help, since the chips have got to be on the move till they are fully coated Rectification, such as placing of smaller premixed chips over high and bald spots, should be done after the main aggregate is almost fully coaled and has taken up, more or less, its final position in hollows and the rest of the road surface except such places where there is not room enough for accommodating the main aggregate one deep. It is at this stage that premixed chips of smaller grade are laid in bare places, and, under drag broom, they take their proper places except the very highest spots on which still smaller premixed chips have to be placed and in this way the whole surface becomes covered with chips of appropriate size to give a level surface. Broadcasting of the smallest dry chips is to be done after the levelling and covering of the whole area with coated chips is complete. A few further trips of the drag broom (unloaded), make the finest chips get into the interstices of the coated chips uniformly and these do not get coated with binder, as is suggested in last but one para of this section, as they cannot roll and move over the rough surface on top of the precoated chips. Besides, there is hardly likely to be spare binder at the top of coated chips for coating the finer chips unless excessive quantity had been used. The finer chips remain sticking to the interstices of the bigger coated chips below and may or may not be permanently absorbed according as there is or is not spare binder to work up and cover them up. If they

get so absorbed, well and good, otherwise they are sucked up under pneumatic wheel traffic and lost, and a liquid seal, as suggested by the author in para 2, page 163, in connection with work with drag spreader, becomes necessary in this case also.

(17) The direction for opening the road to steel-tyred traffic after a week of completion of the work and after it had been open to pneumatic-tyred traffic in the meantime, does not seem to be practical. For whatever period it is decided to keep off the traffic, it will have to be the same for all vehicular traffic that usually passes in that section of the road. This period need not be the same for all kinds of binders that could be used for such work. In case of hot binders like Road tar or Shelspra B. S., it can evidently be shorter than in case of a cold application cut-back like Socofix. For former, 24 hours and for the latter, 48 to 72 hours according to season should suffice.

(18) In conclusion, I feel there is little to recommend work with drag broom once we have found a better method of work with the drag spreader. Evidently, the author also does not like the various rectifications by hand to be inevitably done in a drag broom work if same has to be done on an uneven surface. In fact it was this aspect and drawback of the drag broom work that led me to try hand-laid premixed chipping carpet work and it proved so straight forward and simple and gave such encouraging results that I find no justification in doing any more work with drag broom even when conditions do not admit of using the drag spreader. With greater facility with the use of the drag spreader, there is still less justification for going in for drag broom work. Even the cost of work done with the drag broom compared to hand-laid premixed chipping carpet is against the former. For the same quantity of chips, less binder will be required in a premixed chipping carpet work than in road-mix seal work and labour cost of former is found to be about three fourth of the latter. In fact, the labour cost of hand-laid premixed chipping carpet is only slightly more than that of surface painting and chipping work and the resulting surface is much substantial and there is no reason why the former should not replace the latter. Considering the longer life of a premixed chipping carpet, it should prove cheaper than the surface painted chipping work. Therefore, it seems that, instead of trying to popularise the use of drag broom work, as is suggested by the author, attempt should be made to remove the fright about premix work and the wrong notion of its being more expensive. In fact, I feel that the description and specification of the drag broom work should not have found a place in the author's notes on drag spreading work.

Reply of Mr. W. L. Murrell, O.B.E., (Author), to the above comments.

Replies are para by para.

1. As regards the Delhi work, I was rather disappointed, as the road surface being corrected by drag spreading was not very rough. The depth of the hollows was scarcely half an inch between bumps 8 to 10 feet apart. A road surface with 1" to 2" hollows between bumps 4 or 5 feet apart would have afforded a much more vivid demonstration of the possibilities of this process.

2. There are really two papers in one. It is not meant that road-mix seal is a competitor to the drag-spreading of a premix. Nor is it meant that either process is to compete with ordinary surface-treatment. The three processes are applicable in three different conditions.

This I have tried to explain at the top of pages 173 and 181.

Besides this, an essential difference is that the drag spreading of premixed chips does not afford a seal or water-proofing, whereas this is one of the main functions of a road-mix seal. Many, beside Mr. Amir, appear to overlook this point.

3. Another reason for my treating the road-mix seal process is to try and keep the process in view. The defects in India are in the plant, and not in the process, as I tried to point out on page 167. If any Province had 400 or 500 miles of water-bound roads to modernise chiefly for motor traffic, it would pay that province to get proper road mixers and adopt road-mix seal.

From what I can see of it, Madras has recently "missed the bus" in this respect.

4. Last portion of the second para on page 160.

With due respect for Mr. Amir's doubts, the use of a drag broom is standard practice in other countries using such binders.

5. Para on "Tack Coat", page 162.

It depends on the kind of priming that has been done.

If hot No. 1 Road Tar and sand priming has been done, such as I introduced in Chota Nagpur, and it has been opened to traffic for a few months, or if the cold priming is thin and has penetrated well, leaving a dull and lean-looking surface, a tack coat should be done.

But if a good liberal dose of a fairly heavy primer like Shell Primer or Shalimar Cold Tar Primer has been used, leaving the surface definitely sticky, no tack coat is required.

6. Para 5 on page 166.

Vide my reply in para 4 above.

7. Para 7 on page 166.

I simply stated what the Australians do, and I think the fact is mentioned in their specifications, a copy of which is to be had—Catalogue No. IRC 69—in the Roads Congress Library.

If Mr. Amir refers to page 186, he will see that my specification for all aggregate to be road mixed provides that spreading shall be done by hand.

8. "The Process" para 2, page 168.

Mr. Amir, perhaps rightly, quarrels with the word "most". In writing "most," "I meant the major part".

Evidently, Mr. Amir has overlooked the table on page 182 and paras 4 and 5 on page 186

9. "The Process," para 3, page 168.

I disagree entirely, and would suggest that Mr. Amir actually try the method before critising it.

10 "Comparative statement" on page 171.

The binder is mentioned in the relative detailed specification.

Evidently Mr. Amir does not quite understand the table given on page 171.

The cost of labour per hundred square feet is given in the item which involves the factor "c".

Thus, if a cooly cost six annas or Rs. 0.375, per day the total cost of labour for priming, including contractors supervision and profit would be Rs. 0.56 × 0.375, or Rs. 0.21.

11. Para under "Drag Broom" page 181.

I quite agree with Mr. Amir that a drag broom on each end of the roller would speed the process up a lot. The required brooms need a little rigging, however, and it would be best to begin with a single broom.

12. Para 2 under "Bottom or seal Binder" page 185.

If Mr. Amir will use the perforated kerosine-tin pourer, he will find that the application is almost as quick as with an ordinary baffle pourer, and the process gives more even application besides reducing brooming to almost nil.

13. I do think that people who have not tried a process or a proceeding should not say or imply that it cannot be done.

14. Para 3, page 188.

I have always worked in the manner described in the specification. It works all right. A practical point in working from the edges first is that this prevents any binder from escaping at the edges.

15. Para 8, on page 188.

I cannot agree with Mr. Amir.

I have studied this question of rectification a good deal, and I have come to the conclusion that most rectification is due to using too little material, or due to trying to use this process on a road that is too rough. I think Mr. Meares, the pioneer of this process, tried

to economise too much in order to make the process a competitor of ordinary surface treatment.

Mr. Amir has confessed that he does not like the process. It would seem that he has not analysed the causes of the difficulties and troubles he has met with.

16. Para 1, under "Simultaneous mixing and rolling" page 189.

It is difficult to see how Mr. Amir can get the impression he mentions. He will find at the foot of page 187 that hand dragging has already been done.

As regards the rest of Mr. Amir's remarks under this para, they are evidently based on his experience with quantities which were much too small considering the roughness of the road surfaces with which he was dealing.

17. This refers to the last para on page 189.

With due regard to Mr. Amir, it should be possible to keep steel-tyred traffic off the road. Indeed the matter is easy where *likhs* are provided for carts.

As regards using hot binders wholly for such work, as implied by Mr. Amir, I have never heard of their use.

18. My reply under para 2 above may please be seen.

Comments by Mr. N. Das Gupta (Calcutta).

Mr. Murrell's very interesting paper is of utmost value to Engineers entrusted with the work of road maintenance with a fixed sum of money. It should be read very carefully by all road Engineers in India. As has been pointed out by the author, large savings can be effected by adopting one of these specifications and this is a very important consideration for improving the *road-rupee ratio*.

Generally, my comments will be directed to the nomenclature, design of the drag-spreader and the material for drag-spreading work. After dealing with these broad points, I shall express my views on minor points either agreeing or dissenting with the author. I feel a little proud to mention here that the author has personally invited me to comment on his paper. I have, therefore, read his paper as thoroughly as I could.

Nomenclature. Personally speaking, I do not like the title of the paper. The words "Drag-brooming" and "Drag-spreading" really mean certain operations but not a particularly classified type of construction.

In these two processes we are actually laying a carpet of coated stone chips. In "Drag-brooming" we are mixing stone chips whereas in "Drag-spreading" we are spreading premixed stone chips on the road

surface with Drag-spreader. I would, therefore, suggest the following names for the specification :—

> "Construction of Asphalt or Tar macadam surface by Drag-spreading/Drag-brooming" and a "Bituminous Macadam construction with a Drag-broom/Drag-spreader" for the title of the paper, the word bituminous being used in its true definition and covering Tar products In either case the construction is of the Macadam type, the stability of the carpet depending on the interlocking of stone chips and the binding properties of the bituminous material used.

Design of Drag-spreader. From my own experience, I found three principal short-comings of a Drag-spreader of the existing design :

1. Its inability to allow super-elevation at the curves. The blade shown in plate 2 is with a camber at the centre. This difficulty may be obviated by having another steel blade with necessary super-elevation at one edge. This super-elevation may be accurately calculated from the usual formula—

$$e=\frac{W\,V^2}{g\,R}$$

where e=Super-elevation in feet,

W=Width of the road in feet,

V=Velocity of the vehicle in feet per second,

R=The radius of the curvature of the road in feet.

Usual practice, however, is to keep the same rise in the centre of the road and to elevate the outer edge by twice the central rise above the road surface. Taking the author's example, the super-elevation will be 2 inches at the outer edge of the curve of the road surface and therefore, the blade should be straight from edge to edge.

2. The other short-coming of the present design is the inability to adjust its width to the road width. It is very common to witness the road width varying from say 20 feet in the town to 18 or 16 feet in the suburb and then probably to 12, 10 or 9 feet outside town limits in the case of a road emerging out of a city. Also, different widths are adopted for different roads in the same district, which may be due to economic considerations or due to variation in the amount of traffic on these roads. It is, therefore, desirable to provide some adjusting device on the Drag-spreader or Drag-broom consistent with the necessary rigidity of these appliances. Such an arrangement is shown in fig. 1, facing page 190k.

Thirdly, the adjustment of the drag-spreader for different thicknesses of the carpet may be considerably improved by adopting the arrangement shown in fig. 2, facing page 190l.

The blade carrier is strapped by a 3/8 inch mild steel plate. Another 1/2 inch plate bent twice at right angles is screwed on to the runner frame by four wood screws. The timber blade with its steel edge is suspended by means of a bolt passing through a slot in the strap plate and is capable of being lifted up or lowered by the nut on top of the Z shaped plate fixed in the runner. In the design presented by the author the adjusting nut is at the sides of the runners and the blade is held up by friction only. With long periods of work the blade may slide down slightly thus decreasing thickness of the carpet to be laid. In the suggested design, carpets from ½ inch to 2½ inches may be laid.

Materials. Referring to page 164 of the paper regarding binder, I would state that recently experiments of drag-spreading on the Sitamarhi Road were conducted with Socofix, Socony Asphalt Grade 105, Tar No 3 and Tar No. 3A. I believe the details regarding the use of these materials would be of interest to all Road Engineers

Experiments with the first two materials were conducted by me with the assistance of the Engineering staff of Muzzaffarpur District Board and were witnessed by Mr. Murrell himself, Mr. B. B. Gupta, Executive Engineer, P. W. D., Rai Bahadur U. S. Jayaswal, Rai Saheb Sahay, Assistant Engineer, P. W. D. and P. W. D. overseers.

Socofix, which is a medium-curing cut-back asphalt containing nearly 80 per cent of bitumen, was used cold at the rate of 3 3 pounds per cubic foot of ½-inch stone chips The mixing was done by hand-operated drum mixers. Each batch of 3 cubic feet required only 2 minutes on average The premixed chips were carried by wheel-barrows and delivered in front of the drag-spreader.

Socony Asphalt Grade 105, which is a steam refined asphalt of 80/100 penetration, was heated to 375 degrees Fahrenheit in steel drums over ovens dug at the road flank. 10 pounds of this asphalt was taken out to which was added 1 pound of Socosol and well-mixed up by stirring with a stick. The asphalt with Socosol, was then poured over a batch of 3 cubic feet of 1/2-inch stone chips loaded in a drum mixer For better and quick mixing, half the quantity of asphalt was added to the stone chips, the drum mixer rotated for 2 minutes and then the balance of asphalt was put and the mixer turned again until all the stone chips were thoroughly coated. Each batch took 5 minutes to mix on the average. The mixed chips were carried as usual by means of wheel-barrows and delivered in front of the drag-spreader.

With Socony asphalt, the rolling was done almost immediately after spreading, while with Socofix rolling was done after 4 to 6 hours. This was due to higher percentage of solvent contained in Socofix in order that this material may be used cold.

As regards the working of the drag-spreader and the organisation of labour, I would suggest that it would be sufficient and economical to

operate 6 mixers With too large a number of mixers, there would be too many coolies resulting in confusion, less effective labour and excessive labour cost Twenty or thirty mixers would require a large area and due to insufficiently wide flanks generally available, the lead would be excessive. Also with too rapid a progress of drag-spreading work, it would be necessary to move the mixers forward constantly, adding to the confusion. With six mixers, it is possible to get 1000 cubic feet of mix per day which would cover 10,000 square feet of road surface one-inch thick.

The labour required for the output per day would be as detailed below :—

Gang 1.	1.	Screening stone chips and filling measures	4
	2.	Carrying stone chips to mixers	6
	3.	Filling in asphalt and weighing the same	1
	4.	Carrying asphalt to mixers	2
	5.	Turning Drum mixers	24
	6.	Carrying premix in wheel barrows	3
Gang 2.	7.	Pulling Drag-spreader	5
	8.	Wetting Roller Wheels	2
	9.	Carrying water for boiler and roller wheels	3
	10.	Touching up carpet after dragging and rolling ..	2
Gang 3.	11.	Cleaning road surface	
		(a) with wire brushes	6
		(b) with bass brooms	2
		(c) with soft brushes	6
	12.	Applying Primer or tar coat	4
			70 men

For carrying stone chips, the easiest, accurate and economical method is to fill in a wooden box 1 foot in all dimensions, provided with two parallel wooden handles at two sides and let two coolies carry the box to mixer, each holding the ends of the two long handles. This method is adopted by contractors in the United Provinces, and is very quick and economical.

Now, assuming the average daily wages of each cooly to be 6 annas, the total labour charge would be Rs. 26/4/- or Rs. 0/4/3 per 100 square feet, whereas, doing the same work without a drag-spreader would have cost nearly twice as much. I have deliberately shown all labour as men as I am of opinion that the speed, efficiency of a work and its success are hampered by employing women or boys who appear to be cheaper. I would further suggest that in all contracts it should be explicitly mentioned that all labour must be full-grown able-bodied men. The boys or women employed cannot work as hard as men, however chased, and taking the cost of labour on the work done, it can be found that they are not really cheap.

Referring to page 170 of the paper, where the author discusses the other uses of Drag-spreader, I think it will be advisable to use a straight asphalt instead of an emulsion. There are so many miles of good grouted roads near about Calcutta carrying intensely heavy bullock

cart and lorry traffic that I am sure this method of drag-spreading dry stone metal followed by grouting with hot asphalt will be a success, provided, of course, good hard stone is used. It may interest Mr. Murrell to know that I recommended this specification to the Executive Engineer, Patna for the same road with the only difference that the stone metal would be hand-spread instead of drag-spread but unfortunately still, trial and error methods are being tried on the road which carries heavy cart traffic. With Gaya stone metal, there is no reason why this specification would not yield a strong and durable surface.

Referring to last paragraph on page 172, I would refer Mr. Murrell to page 29 of the booklet entitled "Asphalts for India"* published in October 1939 by Standard-Vacuum Oil Co., India. Mix-in-place construction using a dragbroom on rough water-bound surface has been described there For a bituminized surface the quantities of Socofix should be reduced according to the age and condition of the surface to be treated.

Reply of Mr. W. L. Murrell, O.B.E., (Author), to the above comments.

Nomenclature. Mr. Das Gupta objects to the title of the Paper. I would like to point out that the processes have been properly named at the commencement of the detailed specifications on pages 173 and 181.

Mr. Das Gupta, like very many others, has apparently missed a most important point in that the road-mix-seal process provides a seal as well as a carpet. A carpet by itself cannot be relied on to waterproof a pavement.

Design of the Drag Spreader. The spreader as shown in Plate No. 2 with the Paper is fully designed to cope with super-elevation jobs. Mr. Das Gupta might please again read the paras at the foot of pages 158 and 160.

I quite agree that it would be very nice to have a drag spreader of adjustable width so as to cope with roads of varying width. But Mr. Das Gupta's design is of no help in this respect. It is no use lengthening the blade unless the distance apart of the runners or skids is also varied. No doubt this could be done but it would vastly complicate matters. The present aim is for simplicity and cheapness of plant.

The drag spreader as now designed is so cheap that more than one can be purchased for each sectional officer or overseer. And 8 feet spreader will suffice up to 10 feet, the two one-foot wide side stretches being spread by hand. A 10 feet wide spreader will similarly do up to 12 feet.

For 16 feet wide roadways, two runs are taken with the 8 feet spreader.

As regards the blade adjustment proposed by Mr. Das Gupta, I would much prefer the simpler one already shown in the plans with the Paper.

* The booklet is available in the library of the Indian Roads Congress. *vide* Catalogue No. IRC, 198.

Mr. Das Gupta's proposed design is rather elaborate and unless a system of double nuts were used it would not prevent the blade from rising, and thus riding over the premix.

Materials:—On page 164, I mentioned Messrs. Burmah Shell Products because certain engineers of that Company were the first to appreciate the great advantages of the drag spreader both in Australia and India, and because carpets drag spread with Shell products in India a year or so ago are standing up very well.

Now, Socony and Shalimar products have been used and, so far as can be seen, they are quite satisfactory.

Labour :—I wish to thank Mr. Das Gupta for his notes on the organisation of labour for drag spreading. My paper falls a good deal short of what is possible in the matter of labour organisation, and Mr. Das Gupta has capably supplied the deficiency.

It is a fact that good organisation can greatly reduce the number of drum-mixers, and consequently the cost of the work.

The secret lies in loading the drum quickly and in taking the premix by the quickest possible means from the drum to its place in front of the spreader blade.

Next, there is the question of getting the stuff from the drum-mixer to its place on the road before the spreader blade.

It will be noticed that, under the heading "Feeding the Drag Spreader" (page 177), I have specified that "the premix shall be carried promptly in clean iron *karais* to the drag spreader."

As a matter of fact, wheel-barrows are used in Australia, the barrows just passing under the draw-bar pipe, and the premix being spilt in front of the blade by tilting the moving barrow.

When drawing up the specification I thought that wheel-barrows were too scarce in India to include them in the specification but, on a recent job, two such turned up by accident and they doubled the rate of spreading. The barrows were pushed under the mixing drums and the premix was emptied directly into them from the drum.

For 'Loading' and "Feeding the Drag Spreader," I would therefore, refer Mr. Das Gupta to my remarks on page 190 (a).

As regards Mr. Das Gupta's suggestion that men only should be employed, I think that, though there is much in what he says, the matter might be left to the engineer on the spot to decide.

I would like to see a straight asphalt tried for grouting chips drag-spread as a smoothening coat, for I am always open to conviction. But I do not see how the requisite amount of such a binder could run into the hollows in the rough road surface in order to augment the binder there and so enable it to cope with the excess chips in those hollows.

I thank Mr. Das Gupta also for pointing out the specification on page 29 of the booklet "Asphalts for India."

Mr. W. L. Murrell, O.B.E., (Author) has offered the following further remarks in conclusion :—

As regards the road-mix seal process, I feel that I have failed rather miserably in "putting this across". Most road engineers appear to consider it as a mere alternative to the drag spreading of a chippings premix, or to an ordinary surface treatment.

I only wish that these road engineers could see the many hundreds of miles of water-bound road which I have seen which were too rough for ordinary surface treatment, and yet not so rough that they must be reconsolidated before doing a surface treatment. It is in these hundreds, or thousands, of miles that road-mix seal has come into its own.

Perhaps I have been too optimistic in believing that the cheap India-made drag broom could perform a sufficiently large portion of the duties of a proper road mixer.

On the other hand, as regards the spreading of a chippings premix by means of the drag spreader, I do feel the greatest satisfaction that, with the blessing of the highway engineers of both the bitumen distributors and of the tar distributors, the process has come to stay, and do its share towards improving the *road-rupee ratio.*

Those who have followed what has been done to date as regards drag spreading will by now have seen that the process is "O.K." by bitumen.

I have been promised notes and photographs of successful drag spreading with Indian tar products; but it appears that they will not arrive in time to receive detailed description or reproduction in this volume of the Proceedings.

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